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Yield and Quality of First-Year Corn Silage Following Alfalfa Stand Termination as Affected by Tillage, Herbicide, and Nitrogen Fertilizer

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YIELD AND QUALITY OF FIRST-YEAR CORN SILAGE FOLLOWING ALFALFA STAND TERMINATION AS AFFECTED BY TILLAGE, HERBICIDE, AND NITROGEN FERTILIZER

by

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ABSTRACT

Yield and Quality of First-Year Corn Silage Following Alfalfa Stand Termination as Affected by Tillage, Herbicide, and Nitrogen Fertilizer

by

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Utah State University, 2014

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Glyphosate (N-(phosphonomethyl)glycine)-containing herbicides are a common and highly effective method to terminate alfalfa (*Medicago sativa)* stands. With the development and use of glyphosate-resistant (Roundup Ready®) alfalfa, this tool is no longer an option. The purpose of this research was to determine the optimal strategy to rotate from glyphosate-resistant alfalfa into silage corn (*Zea mays*). Studies were conducted in 2012 and 2013 at sites near Cache Junction and Cornish, Utah to determine the effect of tillage type and timing [fall conventional till (FCT), spring conventional till (SCT), fall strip-till (FST), spring strip-till (SST), and no-till (NT)], 2,4-D plus dicamba herbicide timing (fall, spring, in-crop, and a control), and N rate (0, 56, 112, and 224 kg N ha^{-1}) on soil penetration resistance (PR), alfalfa re-growth, and corn emergence rate index (ERI), silage yield, quality, and economic return. The fall, spring, and in-crop herbicide timings across all tillage treatments reduced alfalfa stem count and biomass by at least 95% and 98%, respectively. Tillage reduced PR compared to NT to or near the depth of tillage. The ERI was significantly higher under FCT, SCT, and SST and when herbicides were applied in fall or spring. Silage yield, quality, and economic return were the highest when spring herbicide timing was used with all tillage types and timings and the fall herbicide timing under conventional tillage. Increasing N rates increased crude protein, milk ha^{-1}, and dry matter yield. However, optimal yield and quality can be obtained with no additional N fertilizer. First-year silage corn yield, quality, and economic return can be optimized under fall or spring conventional till, strip-till, and no-till at the spring herbicide timing along with the fall herbicide timing for conventional tillage with no additional N fertilizer.

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PUBLIC ABSTRACT

Yield and Quality of First-Year Corn Silage Following Alfalfa Stand Termination as Affected by Tillage, Herbicide, and Nitrogen Fertilizer

Jason D. Clark

Glyphosate-containing herbicides such as Roundup® are a common and highly effective method to terminate alfalfa stands. With the development of glyphosate-resistant (Roundup Ready®) alfalfa, this tool is no longer an option. The purpose of this research was to determine the optimal termination methods to use when rotating from glyphosate-resistant alfalfa into silage corn. Studies were conducted in 2012 and 2013 in Cache Junction and Cornish, Utah using five different combinations of tillage type and timing (fall conventional till, spring conventional till, fall strip-till, spring strip-till, and no-till), four 2,4-D plus dicamba herbicide timings (fall, spring, in-crop, and a control), and four nitrogen rates (0, 56, 112, and 224 kg N ha^{-1}). These tillage types and timings, herbicide timings, and nitrogen rates were tested to determine their effect on compaction measured by penetration resistance, alfalfa re-growth measured by alfalfa stem counts and alfalfa biomass collected before corn silage harvest, corn emergence measured by an emergence rate index, and silage yield, quality, and economic return.

The fall, spring, and in-crop herbicide timings across all tillage treatments controlled ≥ 95% of the alfalfa stem count and 98% of the alfalfa biomass controlling 44% to 71% more than tillage alone. All tillage treatments reduced penetration resistance compared to no-till to or near the depth of tillage. The emergence rate index was higher

under fall conventional till, spring conventional till, and spring strip-till and when herbicides were applied in the fall or spring. Silage yield, quality, and economic return were the highest when spring herbicide timing was used with all tillage types and timings and the fall herbicide timing under conventional tillage. Increasing nitrogen rates increased crude protein, milk ha^{-1}, and dry matter yield. However, optimal yield and quality can be obtained with no additional nitrogen fertilizer. First-year silage corn yield, quality, and economic return can be optimized under fall or spring conventional till, strip-till, and no-till at the spring herbicide timing along with the fall herbicide timing for conventional tillage with no additional nitrogen fertilizer.

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INTRODUCTION

Alfalfa (*Medicago sativa*) and corn (*Zea Mays*) are two of the most important crops in the dairy production areas of the Intermountain West. Corn hectares harvested have increased from 72,874 ha to 110,931 ha (52% increase) for silage corn and from 24,695 ha to 61,132 ha (147% increase) for grain corn from 2002 to 2013 in Utah and Idaho (NASS, 2014). Most information on corn production comes from the Midwest and Northeastern areas of the U.S. where soil conditions, mean temperatures, and growing seasons are much different than the Intermountain West. With the increase of corn hectares there is a need for corn production research under semi-arid, irrigated conditions characteristic of the West. Corn is most commonly grown in rotation with alfalfa because of alfalfa's ability to create good growing conditions for corn by breaking up compacted areas, increasing total pore space, opening channels for water percolation and soil organisms to move, and adding nitrogen (N) to the soil thereby decreasing the amount of fertilizer needed (Bolton et al., 1976, 1979; Stone et al., 1987; Rasse and Smucker, 1998; USDA NRCS Plant Materials Program, 2006).

Alfalfa stands are commonly terminated by herbicide(s), tillage, or a combination of both. The use of glyphosate (N-(phosphonomethyl)glycine) herbicide alone, or coupled with tillage, has been shown to provide excellent control of alfalfa (Buhler and Mercurio, 1988; Bullied et al., 1999; Malhi et al., 2007). Alfalfa with resistance to glyphosate (Roundup Ready ®) has recently been commercialized and is now being planted widely throughout the West. In fields where this technology is employed, glyphosate is no longer an option for alfalfa stand termination. The mixture of 2,4-D

(2,4-dichlorophenoxyacetic acid) plus dicamba (3,6-dichloro-2-methoxybenzoic acid) has also been shown to be highly effective in terminating alfalfa (Moomaw and Martin, 1976; Buhler and Mercurio, 1988; Van Deynze et al., 2004). According to the labels, this new herbicide combination will require different application timings due to restrictions on application timing and subsequent harvesting, feeding, tilling, and planting. For example, 36 hours after spraying glyphosate the alfalfa can be harvested then tilling and planting can take place, whereas 2,4-D plus dicamba application can occur after 10- to 15-cm of regrowth has occurred after alfalfa harvest. Tilling and planting must then be delayed another 7 to 14 days. Some studies showed that alfalfa was controlled equally when terminated with tillage or herbicides in the fall or spring (Moomaw and Martin, 1976) while others showed spring was better than fall (Bullied et al., 1999; Malhi et al., 2007). Little research exists on how a fall, spring, and in-crop herbicide application timing compare to one another in controlling the alfalfa and optimizing silage yield and quality.

Conventional tillage systems completely turn the soil over and control alfalfa and weeds (Mohr et al., 1999; Malhi et al., 2007), increases corn emergence rates (Erbach, 1982; Al-Darby and Lowery, 1987), decreases N volatilization, and increases potential mineralization and nitrification (Doran, 1980; Cogle et al., 1987; Janzen and McGinn, 1991; Mohr et al., 1998c). However, it also decreases soil moisture, increases erosion (Mohr et al., 1999), decreases organic matter, overall productivity of the soil (Entz et al., 1995), soil structure, and increases potential for soil crusting (Bullied et al., 1999). To mitigate these negative effects producers, have been moving to conservation tillage techniques such as no-till (NT) and strip-till. These systems leave more plant residue on the soil surface, maintain soil structure, decrease the potential for erosion (Moyer et al., 2003), improve soil moisture, decrease nitrate (NO_3) leaching, and decrease nitrous oxide greenhouse emissions (Malhi et al., 2009). However, NT systems rely heavily on herbicides to control alfalfa, have a higher bulk density, lower proportion of fine aggregates in the 5- to 10-cm depth (Vyn and Raimbult, 1993), and tend to have lower corn emergence rates (Al-Darby and Lowery, 1987; Licht and Al-Kaisi, 2005). Strip-till systems are able to relieve compaction (Vetsch and Randall, 2002) while maintaining some residue on the soil surface, and have similar emergence rates as conventional tillage (Aflakpui et al., 1994; Shinners et al., 1994; Beyaert et al., 2002, Licht and Al-Kaisi, 2005). Herbicides are still heavily relied upon to fully control the alfalfa. Strip-till has been shown to have greater silage yields than NT and similar to conventional tillage (Randall et al., 2001; Vetsch and Randall, 2004). In one year of another study, NT yields were significantly less than conventional tillage, but similar in the next year (Aflakpui et al., 1993). More data is needed comparing conventional tillage, strip-till, and NT silage yields to better determine which systems work well under the semiarid, irrigated conditions in the Intermountain West.

Silage yields after alfalfa did not increase with the addition of fertilizer N in conventional tillage (Rasse and Smucker, 1999; Basso and Ritchie, 2005) or NT systems (Rasse and Smucker, 1999; Yost et al., 2013a). Yost et al. (2012) reviewed the literature and found that these findings are correct 91% of the time when the alfalfa stand has ≥ 43 plants m^{-2} at the time of alfalfa termination. An example of the other 9% is when a corn silage trial maximized its yield with a 40 kg ha^{-1} rate of fertilizer N (Yost et al., 2012). It is important to know what field conditions will elicit an N response. Soon and Clayton (2003) determined that NT systems that fail to produce similar yields as conventional tillage, without N, can produce similar yields by adding N at the beginning of the season. On the other hand Aflakpui et al. (1993) did not find any tillage by N rate interaction effect on yield, and suggested NT yields cannot equal conventional tillage yields by only increasing nutrients. Research is needed to determine if strip-till or NT systems require additional N and if there are any conditions in the Intermountain West that may require additional N fertilizer for first-year silage corn after alfalfa.

Silage quality may be affected by termination method and timing. A study by Aflakpui et al. (1994) comparing conventional tillage vs. NT found that tillage system did not affect crude protein percentage, calcium, phosphorus, potassium, magnesium, total digestible nutrients, acid detergent fiber (ADF), or net energy of lactation (NEL). The amount of alfalfa re-growth and timing (fall or spring) of terminating alfalfa by tillage, herbicide, or both has been shown to not affect corn silage, corn grain, cob, or stover yield in response to N (Barnett, 1990; Carter et al., 1991; Aflakpui et al., 1994; Rasse and Smucker, 1999; Lawrence et al., 2008; Yost et al., 2012). Research is needed to determine if strip-till or an in-crop herbicide timing affect silage quality.

The rates of N needed for maximum dry matter yields have been shown to be different from that of highest forage quality (Cox et al., 1993). Lawrence et al. (2008) showed that to produce the economically optimum quality and yield for corn right after alfalfa a small amount of starter N fertilizer is needed regardless of tillage type. Nitrogen fertilization increased crude protein and soluble protein, but it did not have an effect on neutral detergent fiber (NDF), digestible neutral detergent fiber (dNDF), lignin, starch, or estimated milk production (Sheaffer et al., 2006; Lawrence et al., 2008). Research is lacking on 1) how fall and spring NT, strip-till, and conventional tillage, and fall, spring, in-crop, and no herbicide timing respond to increasing N rates, 2) if there are any interactions between these factors, 3) how they compare to one another in the yield and quality of corn silage they produce, and 4) what combination of alfalfa termination methods when rotating into silage corn will optimize yield and quality economically.

Fertilizer N recommendations for corn after alfalfa are lower than corn following corn because alfalfa adds N to the soil and has the ability to continue to add N as it decomposes through the corn's growing season (Carter et al., 1991; Aflakpui et al., 1994). The Corn Belt states of Indiana, Iowa, Michigan, Minnesota, Ohio, Wisconsin, and Minnesota give an N credit of between 45 and 168 kg ha^{-1}, depending on the alfalfa plant density when the stand is terminated (Rehm et al., 2006). These recommendations are different from those of Utah and Idaho. Idaho gives a credit of 33-112 kg N ha^{-1} depending on the alfalfa density (Brown et al., 2010). In Utah, the N credit is 112 kg N ha^{-1} (Topper et al., 2010). With a yield goal of 20.7 Mg ha^{-1} the total fertilizer recommendation for silage corn is 224 kg N ha^{-1} (Cardon et al., 2008). The average cost of N fertilizer has increased from US$0.25 kg^{-1} in 2000 to US$0.93 kg^{-1} in 2013 (USDA Economic Research Service, 2013). This increase in price has made producers much more conscious about the amount of fertilizer that they apply to their fields. If the N credit can be increased to that of the Cornbelt states, Utah and Idaho producers would save approximately US$52.00 ha^{-1}. If no N is needed then producers could save US$104.00 ha^{-1}. The N credit given to alfalfa in the Intermountain West needs to be reviewed to determine if it needs to be updated.

The objectives of this research were to 1) determine the percent alfalfa control, corn emergence rate index, penetration resistance of the soil, and corn silage yield, quality, and economic return of different combinations of tillage types and timings, herbicide timings, and N rates, 2) determine if first-year corn after alfalfa based on termination method and timing requires added fertilizer N to optimize quality, yield, and economic return and, if so, how much, and 3) determine if there are any interactions between tillage type and timing, herbicide timing, and N rate.

LITERATURE REVIEW

History of Alfalfa

Alfalfa (*Medicago sativa)* has been cultivated since recorded history began and potentially longer and now grows in most areas of the world (Hanson, 1975). It is thought to have originated in the areas of Asia Minor, Transcaucasia, Iran, and the highlands of Turkmenistan. The Persians brought alfalfa to Greece to feed their chariot horses in the 4th century B.C. In the 2nd century B.C. the Romans received it from the Greeks. In 126 B.C., China was looking for a better feed for their horses so they took seed with them from the Turkestan area. Alfalfa did not spread much more until the 16th century when it spread through most of Europe starting in Spain and ending up in Russia by the 18th century. The Spanish and Portuguese brought alfalfa seed with them to Mexico in the 16th century. It was first taken to the Northeastern part of America but had little success because of the high acidity of the soils in the area. In the 1840s, missionaries took the seeds with them from Mexico and into Texas, Arizona, New Mexico, and California where it thrived in these hot, dry areas. From there, it spread east into Utah (Bolton et al., 1975).

Alfalfa Production and Benefits

Alfalfa is one of the most abundant crops grown in Utah and Idaho. In 2013, 230,769 ha and 465,587 ha of alfalfa were harvested for dry hay or haylage in Utah and Idaho, respectively (NASS, 2014). Alfalfa is a long lived perennial legume that has a tap root that penetrates deep into the soil that is able to access deep water and nutrients and break up compacted soil layers. When these roots die and decay the root channels that remain are used for water percolation, movement of soil organisms, and channels for the roots of the next crop to follow (Stone et al., 1987; Rasse and Smucker, 1998; USDA NRCS Plant Materials Program, 2006). Alfalfa forms a symbiotic relationship with Rhizobium bacteria that infects the alfalfa roots forming nodules where the bacteria fix atmospheric Nitrogen (N) and make it available to the plant. When the plant begins to decompose this N becomes available to the next crop reducing the amount of fertilizer needed (Bolton et al., 1976). Alfalfa also improves soil structure, increases organic matter, and breaks up disease cycles (Ketcheson, 1980). Other benefits include reducing soil salinity, soil erosion, and improving soil moisture (Stinner and House, 1989; Agriculture Canada, 1991; Cutforth et al., 2002).

Alfalfa Rotation

Most alfalfa stands are terminated three to five years after they are established due to weed infestations and/or a stand density that falls below an economic threshold. The common practice in Utah is to rotate out of alfalfa for one to two years to give the autoalelopathic substances excreted by alfalfa roots a chance to decompose or leach from the rooting area. Cereal grains such as wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), or corn (*Zea mays*) are planted as the rotational crop. These are high N-using crops that are able to use the increased N in the soil due to the decomposition of the previous alfalfa stand. This decreases the amount of N that could be leached from the rooting zone and cause environmental damage (Carter et al., 1991). It was shown in a four-year rotation study that total pore space and air space increased with a two-year rotation of alfalfa increasing the following corn crop yield compared to a continuous corn rotation (Bolton et al., 1979). Other rotational benefits include a reduction in insect, disease, and weed pressure. Rotating from a broadleaf to a grass crop also allows producers to use herbicides with modes of action that are not registered for use in alfalfa.

Silage corn or grain corn is the common rotational choice after alfalfa in the dairy producing areas of Utah and Idaho and has been increasing in the amount of hectares that are planted each year after alfalfa. Utah produced 16,194 ha of silage corn and 6,477 ha of grain corn in 2002 increasing to 19,838 ha of silage corn and 12,550 ha of grain corn in 2013. Idaho produced 56,680 ha of silage corn and 18,218 ha of grain corn in 2002 increasing to 91,093 ha of silage corn and 48,582 ha of grain corn in 2013 (NASS, 2014). This increase in hectares of corn grown in Utah and Idaho has led to a demand for corn production research conducted locally under semi-arid, irrigated conditions characteristic of the West.

Termination

Alfalfa regrowth can be a serious weed in corn. Studies have shown that >90% of alfalfa needs to be controlled during the first three weeks after corn planting or corn yields will be reduced (Moomaw and Martin, 1976; Mercurio and Buhler, 1985). Alfalfa stands can be terminated by using tillage, herbicide(s), or a combination of both. Tillage has been the most common way to terminate alfalfa stands for years. Tillage helps to incorporate organic matter, control weeds, and break up compacted areas. From a negative standpoint, tillage can decrease soil moisture, increase erosion (Mohr et al., 1999), decrease organic matter, decrease overall productivity of the soil (Entz et al., 1995), decrease soil structure, and/or increase soil crusting (Bullied et al., 1999). Termination with herbicides keeps plant residue on the surface and maintains soil structure, thereby decreasing erosion (Moyer et al., 2003). Herbicide termination also improves soil moisture, decreases potential for nitrate (NO_3) contamination of groundwater, and decreases nitrous oxide greenhouse gas emissions (Malhi et al., 2009).

Moldboard plowing followed by one or two disking operations and then preparing the seedbed with a harrow or roller harrow has been the standard tillage procedure to terminate an alfalfa stand. This type of tillage has been shown to reduce alfalfa biomass and plant density sufficiently to obtain optimum corn yields (Moomaw and Martin, 1976; Smith et al., 1992; Moyer et al., 2003). Two passes with a rototiller also resulted in similar alfalfa control (Bullied et al., 1999). Because of the high cost of labor, time, and fuel, producers have been moving to other less intense methods of conventional tillage (CT) such as replacing the moldboard plow with one pass with a ripper followed by a pass with a disk, disking the field once or twice, or using disk and shovel cultivation. These newer techniques lower the labor, time, and fuel costs, but to adequately control alfalfa biomass it has been shown that these less intense tillage operations may require the addition of an herbicide application (Moyer et al., 2003; Malhi et al., 2007).

Herbicides alone have also been shown to adequately control alfalfa. Glyphosate (N-(phosphonomethyl)glycine) has been one of the most effective herbicides in terminating alfalfa. This treatment consistently promotes a high rate of corn emergence due to increased soil moisture and its ability to reduce alfalfa basal crown area to levels at or below the tillage treatments (Bullied et al., 1999). With the advent of glyphosate-resistant alfalfa, glyphosate-containing products will no longer be able to be used to terminate those alfalfa stands. Bullied et al. (1999) determined that along with glyphosate, dicamba (3,6-dichloro-2-methoxybenzoic acid) and clopyralid (3,6-dichloro-2-pyridinecarboxylic acid, triethylamine salt) also controlled alfalfa equal to or greater than two passes with a rototiller. The herbicide mixture 2,4-D (2,4-dichlorophenoxyacetic acid) plus dicamba was as effective at controlling alfalfa as moldboard plowing (Moomaw and Martin, 1976). In contrast, Malhi et al. (2007) determined that the use of glyphosate plus 2,4-D or clopyralid plus 2,4-D did not provide good control of alfalfa re-growth alone, but that a combination of herbicide plus tillage was needed.

Glyphosate

Glyphosate is the active ingredient in Roundup® herbicides and is one of the most common herbicides used to terminate alfalfa. It was first tested and developed as an herbicide in 1970, by John E. Franz of Monsanto Co. (Franz et al., 1997). Glyphosate works by inhibiting the enzyme 5-enolpyruvyl-shikimate-3-phosphate synthase (EPSPS). This enzyme is located in the shikimate pathway and when this enzyme is blocked aromatic amino acids that are needed for synthesizing proteins and secondary metabolites are reduced, slowly killing the plant (Padgett et al., 1995; Duke et al., 2003). Glyphosate was first marketed in 1974 as a non-selective, broad-spectrum herbicide (Duke and Powles, 2008). The herbicide grew in popularity quickly because it binds tightly to the soil, letting little herbicide move into soil water or ground water (Kjaer et al., 2005). It does not persist in the soil so there are no plant-back restrictions (Steckel et al., 2007). It also has a short half-life, is non-volatile, has little effect on non-target organisms, and a low level of toxicity towards humans and animals (Franz et al., 1997; Duke et al., 2003; Cerderia and Duke, 2006; Steckel et al., 2007; Duke and Powles, 2008).

Since glyphosate is a non-selective herbicide, it has been and is used to kill weeds before planting a crop and in situations where the spray could be directed to avoid the foliage of the desired crop. In 1996, this changed with the deregulation of the first glyphosate-resistant crops. An EPSPS enzyme from *Agrobacterium* sp. strain cp4 was found to be highly tolerant to glyphosate (Padgett et al., 1995). When this gene is incorporated into the crop genome, the cp4 EPSPS coding sequence produces a glyphosate-tolerant form of EPSPS (Combs and Hartnell, 2007). This tolerant enzyme enables the plant to continue synthesizing aromatic amino acids in the presence of glyphosate (Padgett et al., 1995).

Currently, varieties of soybean, canola, cotton, corn, sugar beets, and alfalfa have been developed to be resistant to glyphosate. Alfalfa is newer in the family of glyphosate-resistant crops and was deregulated in 2005. In the first year, 80,000 hectares of glyphosate-resistant alfalfa were planted in the U.S. equaling 5% of the newly established alfalfa stands (James, 2006). In Mar. of 2007, a court issued a preliminary injunction that all sales of glyphosate-resistant alfalfa seed were prohibited because an environmental assessment was prepared instead of an environmental impact statement. Producers who had already bought seed and would be planting it before a certain date were allowed to plant and harvest it, but mandatory practices of harvesting and storing the alfalfa had to be followed. In Dec. 2010, the final environmental impact statement was filed and in Feb. 2011, glyphosate-resistant alfalfa was again deregulated and became available (APHIS, 2011). Since the re-release of glyphosate-resistant alfalfa, approximately 120,000 ha in 2011 and 250,000 ha in 2012 have been planted for a total of 450,000 hectares with a similar amount as 2012 planted in 2013. Of the approximately 8 million ha of alfalfa, roughly 1.5 million ha is replanted each year with about 20% of that being planted with Roundup Ready® alfalfa (James, 2012).

The development of glyphosate-resistant alfalfa brings many benefits to alfalfa production, along with some new challenges. Most of the benefit is had during establishment of the alfalfa stand and at the end of the stand's life. Glyphosate-resistant alfalfa enables a producer to use a broad-spectrum herbicide and have flexibility of when the weeds can be controlled (Rogan and Fitzpatrick, 2004). This provides a way to control the spring and winter annual weeds that normally compete with the young alfalfa seedlings for water and nutrients, increasing forage and seed purity in the establishment year. The increased purity will increase the dollar-per-metric ton value and result in a greater alfalfa yield (Rogan and Fitzpatrick, 2004; Steckel et al., 2007). As the alfalfa stand ages, it naturally thins becoming less competitive against weeds. Glyphosate can then be used to control weeds to help maintain purity (Steckel et al., 2007). Glyphosate resistance also offers the needed weed control options for minimum and NT systems to succeed by providing a cost effective herbicide option (Padgett et al., 1995).

Problems that may arise from this new weed control system could be a shift in the weed population to weeds that are naturally tolerant to glyphosate, or current weeds developing resistance to glyphosate (Duke and Powles, 2008). There are also questions of how glyphosate-resistant alfalfa will be terminated when rotating into another crop. Now that glyphosate cannot be used to control alfalfa what is the best herbicide, herbicide rate, and timing of application? Will there be plant-back or feeding restrictions with these new termination methods? With all of these changes will the glyphosate-resistant alfalfa system be more profitable than the conventional alfalfa system?

Tillage systems

When rotating into corn, the three main methods of tillage used are conventional tillage (CT), strip-till (ST), and no-till (NT). The temperature of the soil is the greatest limiting factor on the germination and emergence of corn When the soil is tilled, residue is buried which allows the soil to absorb more radiation from the sun, causing the soil to warm faster in the spring. Conventionally tilled soils also have higher potential rates of mineralization and nitrification (Doran, 1980). Moyer et al. (2003) determined CT decreased alfalfa density more than NT. In NT systems the residue is retained, thereby decreasing erosion, but the soil stays cooler longer due to the plant residue on the soil surface, thereby decreasing the rate of emergence compared to CT systems. No-till soils have been shown to have a higher potential for denitrification (Doran, 1980). No-till soils can become very hardened if the non-killed alfalfa depletes soil moisture, making it very difficult to plant, which can result in poor seed placement, low germination, and ultimately, lower yield. If soil moisture is sufficient at planting, then NT systems should better be able to withstand drought. Strip-till systems were created to provide erosion control by retaining the vegetation between the rows, and to have soil temperatures similar to CT systems by removing the debris and tilling only where the seed will be placed (Aflakpui et al., 1994; Beyaert et al., 2002; Licht and Al-Kaisi, 2005).

Compaction

Alfalfa stands experience extensive amounts of compaction as they are driven on by heavy machinery during the cutting, raking, baling, and hauling of dried hay. If this compaction is not relieved, it can impact the yield of the corn crop following the alfalfa. It has been shown that CT practices can alleviate compaction and increase yields similar to non-compacted areas (Phillips and Kirkham, 1962). One of the benefits of CT and ST systems is that they have been shown to relieve compaction and create loose, friable root zones to the depth of the tillage implement (Vetsch and Randall, 2002). In a long term study by Vyn and Raimbult (1993) on a silt loam soil, it was shown that 0- to 20-cm soil depth NT had a consistently higher penetration resistance than fall and spring moldboard or chisel plowing combined with secondary tillage. The spring-plow treatments increased in penetration resistance at a lower rate than the fall timings. The NT plots also had the highest bulk density and lowest proportion of fine aggregates in the 5- to 10-cm depth, which can correlate to delayed or lower emergence and growth rates. These findings are supported by Opoku et al. (1997), Janovicek et al. (2006), and Vetsch et al. (2007), all of whom also determined that penetration resistance was significantly higher in the top 15 to 20 cm of the soil or to the depth of tillage compared to NT. After the depth of tillage, there appears to be little to no difference in soil penetration resistance. However, in the study by Vetsch et al. (2007) comparing NT, zone till, ST, and spring field cultivate penetration resistance was similar in the top 8 cm of soil and then from 8 cm to the depth of tillage NT was significantly higher. In the study by Licht and Al-Kaisi (2005) comparing chisel plow, ST, and NT, the penetration resistance of the first 10 cm of soil was similar for ST and NT but greater than chisel-plow. From 40- to 60-cm soil depth ST and chisel-plow were lower than NT. If penetration resistance does not exceed 1.5 MPa, which is the level that root growth becomes restricted (Unger and Kaspar, 1994), then even though NT areas have greater penetration resistance they can still produce similar yields to those of tilled areas (Janovicek et al., 2006). More research is needed in the Intermountain West when rotating from alfalfa into corn comparing penetration resistance of soils under CT (deep ripping and disking combined with secondary tillage), ST, and NT to determine if and how much years of heavy equipment use on the alfalfa field changes soil penetration resistance and if it is enough to affect subsequent corn silage yield.

Germination

A 1^{o}C change in soil temperature can change the growth rate and nutritional status of corn seedlings (Walker, 1969; Barlow et al., 1977). Soil temperatures can vary depending on how much residue is left on the surface, air temperature, and texture of the soil. Surface covers can reduce soil temperatures and reduce emergence rates (Erbach, 1982; Al-Darby and Lowery, 1987). This is done by plant residues reflecting solar radiation and insulating the soil. A minimum of a 20- to 30-cm residue free width is needed, the width of the tilled area of most ST implements, to absorb radiation and increase soil temperature similar to that of an area with no residue (Shinners et al., 1994). Coarse textured soil temperatures change less with decreasing tillage in a colder year compared to a warmer year as shown when CT and ST had similar soil temperatures in a colder year and different soil temperatures in a warmer year. The effect of lower air temperatures on emergence rate has been shown to increase with less tillage on finer textured soils (Beyaert et al., 2002). Soil temperature, emergence rate, and time to 100% emergence were lower in NT compared to moldboard plowing (Al-Darby and Lowery, 1987). In general Licht and Al-Kaisi (2005) found that as tillage intensity increased soil temperatures increased resulting in a higher plant emergence rate index (how quickly plants emerged from the soil and the entire population reached full emergence). However, in this same study, it was found that the change in temperature due to tillage did not improve crop emergence rates. In studies by Moncrief et al. (1991) and Hayhoe et al. (1993), corn emergence was shown to be delayed by two days in NT compared to CT due to decreased soil temperatures. Sindelar et al. (2013) determined that the N rate, or any interactions with N did not affect germination.

Growth Rate and Yield

Twenty-five days after planting, corn plant height was greatest in CT, lowest in NT, and ST was intermediate (Vetsch and Randall, 2002). Aflakpui et al. (1993) found that CT plants were taller than NT plants in the first three sampling dates but similar in the last, and in the second there was no height difference at any of the sampling times. In another study, Beyaert et al. (2002) determined that the type of tillage did not affect the early growth rates, but the late growth vegetative and early reproductive rates were higher in ST and NT. Consequently, initial height may have been lower for the less tillage types, but in the end yields were similar (Carter et al., 1991; Beyaert et al., 2002). This scenario is not always true and appears to vary by location. In a two-year study, one of the years the number of days to mid-silk, harvest index, and yield for NT were significantly less than CT (Aflakpui et al., 1993). Randall et al. (2001) and Vetsch and

Randall (2004) showed ST had greater yields than NT but the same as CT silage and grain yields. Pedersen and Lauer (2003) showed a decrease in corn grain yield by 5% in NT compared to CT. Vetsch and Randall (2002) showed that in the first two years of corn grain production CT, ST, and NT were equal, but if averaged over four years CT was greater than ST, which was greater than NT. However, ST yield was only 3% or less lower than CT while maintaining a larger amount of residue on the soil decreasing erosion. Vetsch et al. (2007) showed that averaging grain yields of corn over four years was greater for ST than CT.

Termination Timing

Timing of alfalfa stand termination is also a factor that must be considered. Alfalfa was controlled equally when terminated with tillage or herbicides in the fall or spring (Moomaw and Martin, 1976). Other studies have shown better alfalfa control in the spring than the fall (Bullied et al., 1999; Malhi et al., 2007). A study by Buhler and Mercurio (1988) showed that a fall treatment of glyphosate resulted in higher soil temperatures at the time of planting and higher corn emergence rates compared to the spring timing. In addition Smith et al. (1992) showed that in three of four years spring killed alfalfa in a NT system had higher residue cover keeping soil dry and cool delaying emergence and lowering grain yields compared to a fall killed NT system, but this was only in the late planting date treatment where residue cover was near 100%. Termination timing was also shown to effect corn growth rate in a study by Aflakpui et al. (1994) where it was determined that the number of days to 50% silking was only significantly less in fall-plowed corn compared to spring plowed in one of two years.

Nitrogen

Nitrogen is important for corn yield and quality because it is the fourth most abundant element in plants, composing between 1 to 5% of total plant dry matter. It is involved in both structural components and metabolic reactions making it a large factor in determining a plants yield and health (Hawksford et al., 2012). Nitrogen is a major part of amino acids, proteins, enzymes, nucleic acids, cell walls, chlorophyll, phytohormones, and secondary metabolites (Schrader, 1984; Hawksford et al., 2012).

When a plant has sufficient N, most of its resources will be moved to the shoot. When N is deficient, the plant will move more of its resources to the roots in order to explore more of the soil environment to find the N needed. This lowers the shoot to root biomass ratio (Anandacoomaraswamy et al., 2002).

When the plant is not able to resupply itself with the needed N through increased root production, it will start to hydrolyze nucleic acids, proteins, chlorophyll, and other N containing compounds leading to leaf senescence (Hortensteiner and Feller, 2002). Since chlorophyll contains N, the plant will also begin to be chlorotic. Plants naturally breakdown proteins and move them from the older plant parts to the younger ones, so chlorosis will usually appear first on the older leaves and then move to the younger leaves (Schrader, 1984). Around 75% of the N in mesophyll cells is located in the chloroplasts where that N is used mainly in the enzyme Rubisco, which plays a large role in photosynthesis (Peoples and Dalling, 1988). When Rubisco is broken down, the plants ability to photosynthesize decreases which inhibits growth (Hawksford et al., 2012). For these reasons, chlorosis and stunting are the two main visual symptoms of N deficiency and lead to lower yield and quality.

N Availability

Besides the number of alfalfa plants-per-square-meter there are several things that can affect the amount of N that becomes available to the succeeding corn crop and when it becomes available. The first is the termination methods used (i.e. herbicides, tillage, or a combination of both). The second is the timing of the termination method. The third is whether the location is rain fed or irrigated.

The first factor that can affect the amount of available N in the soil is the method of tillage. In controlled climate studies it has been shown that when the alfalfa top growth is left on the soil surface 1% of the ^{15}N was recovered by the subsequent crop while 8% was in the soil and 91% in the residue. If the alfalfa is incorporated into the soil then 10% of the ^{15}N was recovered by the crop while 52% was in the soil and 38% in the residue. Termination method did not affect the release of ^{15}N from the roots. In both circumstances 10% was recovered in the crop while 30% was in the soil and 60% in the residue (Mohr et al., 1998a). The amount of N in the soil increases when the alfalfa crop is incorporated into the soil with some form of tillage (Mohr et al., 1999; Moyer et al., 2003; Malhi et al., 2007, 2009).

The increase in soil N may be due to when surface residues are incorporated into the soil they are exposed to larger populations of soil microbes (Cogle et al., 1987) and incorporation reduces the amount of N lost to volatilization (Janzen and McGinn, 1991; Mohr et al., 1998c). Whether the residue is left on the surface or incorporated it affects the timing and amount of N released (Mohr et al., 1998b). Top growth decomposition and mineralization is delayed when the alfalfa is left on the soil surface (Mohr et al., 1998a) decreasing the short term N supply (Mohr et al., 1998b) and lowering the risk of N lost to the environment (Malhi et al., 2009). If the residue is incorporated, it can lead to a high amount of NO_3 being added to the soil through decomposition that can be lost through leaching and denitrification (Mali and Nyborg, 1983, 1986, 1987, 1990; Nyborg et al., 1997). Rasse and Smucker (1999) reported that NO_3 concentrations found in lysimeter leachates and total NO_3 lost to deep drainage were observed to be higher in CT as opposed to NT treated areas.

In studies by Sainju and Sing (2001) in Georgia, USA and another one by Aflakpui et al. (1993) in Ontario, Canada it was determined that the N amount in the soil was higher under CT than NT. This is supported by other studies that showed NO_3 levels in CT treatments were 20 kg greater than NT treatments (Carter et al., 1991; Mohr et al., 1999; Moyer et al., 2003). This may be because the organic N is mineralized slower in a NT system, because the plant residue is not mixed into the soil. The amount of N in the soil using ST compared to CT and NT is unknown.

The amount of N in the soil is important but most important is to know if the decaying alfalfa stand can support the N needs of the following corn crop. In studies in the Midwest, corn grain (Aflakpui et al., 1993; Boawn et al., 1963; Lory et al., 1995; Triplett et al., 1979; Yost et al., 2012) and silage yields (Rasse and Smucker, 1999; Basso and Ritchie, 2005) for corn grown after alfalfa did not increase with the addition of fertilizer N in a CT system. In a NT system, first year corn grain (Triplett et al., 1979; Aflakpui et al., 1993; Stanger and Lauer, 2008; Yost et al., 2013a) and silage yields

(Rasse and Smucker, 1999; Yost et al., 2013a) also did not result in higher yields with added fertilizer N. Yost et al. (2012) determined that the literature shows that these findings are correct 91% of the time when the alfalfa stand has ≥ 43 plants m^{-2}. An exception was reported by Triplett et al. (1979) who found that a 56 kg ha^{-1} rate of N was sometimes needed to maximize corn grain yield. Similarly, Yost et al. (2012) concluded that corn silage yield was maximized with an application of 40 kg ha^{-1} of fertilizer N.

Levin et al. (1987) and Aflakpui et al. (1993) showed that when N was required to optimize yield the amount needed by CT and NT were similar showing that there was no tillage by nitrogen rate interaction leading them to suggest that NT yields cannot be increased to compare with CT yields with increased nutrients. However, Soon and Clayton (2003) determined that NT systems that produce lower yields than CT with no fertilizer N can produce similar yields by adding N at the beginning of the season. Little is known about the N fertilizer needs of first-year corn after alfalfa in the western U.S. and its interactions with tillage and herbicide timing.

The second factor that can affect N levels in the soil is when the alfalfa stand is terminated. The literature shows that the rate that NO_3 is formed in the soil from the decomposing alfalfa is sufficient to meet the N needs of corn over the course of the growing season whether the alfalfa stand is terminated in the fall or spring. (Carter et al., 1991; Aflakpui et al., 1994). These findings are supported by Barnett (1990), Rasse and Smucker (1999), and Lawrence et al. (2008), who also determined that both fall and spring termination timings can provide enough N for the succeeding corn crop. In addition, Lawrence et al. (2008) and Yost et al. (2012) determined that the amount of alfalfa re-growth and timing of terminating alfalfa by tillage, herbicide, or both does not affect silage yield, corn grain, cob, stover, or corn silage yield in response to N.

The third factor that can affect the amount of N in the soil is method of irrigation. Land under flood irrigation required a higher amount of N due to losses through leaching and a lower rate of mineralization resulting from applying more water to the field compared to corn under sprinkle irrigation (Cela et al., 2011; Yost et al., 2013b). Management decisions of when and how an alfalfa stand will be terminated need to be made based on environmental conditions, residue composition, and termination management practices (Mohr et al., 1998a).

Nitrogen and Quality

The rate of N needed for maximum corn dry matter yields have been shown to be different from that of highest forage quality (Cox et al., 1993). Lawrence et al. (2008) showed that to produce the economically optimum quality and yield for corn right after alfalfa, a small amount of starter fertilizer is needed regardless of tillage type. Nitrogen fertilization increased crude protein and soluble protein, but it did not have an effect on neutral detergent firber (NDF), digestible neutral detergent fiber (dNDF), lignin, starch, or estimated milk production (Sheaffer et al., 2006; Lawrence et al., 2008). A study by Aflakpui et al. (1994) comparing CT vs. NT determined that tillage system did not affect crude protein percentage, calcium, phosphorus, potassium, magnesium, total digestible nutrients, acid detergent fiber (ADF), or net energy of lactation (NEL).

Potential Management Implications

Current management practices used to terminate alfalfa when rotating to corn include the use of herbicides and tillage. The most common herbicide used is a glyphosate containing product which is sprayed on the alfalfa a few days before the final cutting in the fall or the first cutting in the spring. When glyphosate-resistant alfalfa stands are being terminated, this will no longer be an option. 2,4-D plus dicamba has been shown to be the most effective herbicide combination with the least amount of restrictions (Van Deynze et al., 2004). This new herbicide combination will require different herbicide application timings compared to glyphosate products due to 2,4-D and dicamba's restrictions on application timing and subsequent harvesting, feeding, tilling, and planting. According to the labels, one of these restrictions is that application of 2,4-D plus dicamba would most likely occur after alfalfa harvest and the alfalfa has regrown 10 to 15 cm. Also tilling and planting would be delayed another 7 to 14 days after herbicide application whereas glyphosate can be sprayed before harvesting the alfalfa and then 36 hours later harvesting, tilling, and planting can take place. If sufficient regrowth has occurred in the fall after the last cutting and the plants are still actively growing, then a fall application is possible, if not a producer must wait until conditions are suitable in the spring. Because producers that want to take their first alfalfa cutting in the spring and then rotate into corn cannot wait 7 to 14 days before tilling and planting without greatly reducing corn yield, an in-crop herbicide application would need to be done after the tillage and planting operations are finished and the needed alfalfa regrowth has occurred. Research needs to be done to determine how termination strategies for Roundup Ready®

alfalfa will affect alfalfa control and the yield, quality, and economic return of silage corn.

The current, common conventional tillage practice used for rotating from alfalfa to corn in Utah is deep ripping the field, disking it, and then preparing the seedbed. As shown in the literature above conservation tillage techniques such as ST and NT are beginning to be used more in order to improve the soil structure, decrease erosion, and decrease production costs. Each of these systems affects the emergence rate, growth rate and subsequent yield of the corn crop differently. Even with all of these differences the yields have often been shown to be similar (Carter et al., 1991; Aflakpui et al., 1994; Beyaert et al., 2002), however there are instances in the literature where yields are significantly different between tillage types (Randall et al., 2001; Pedersen and Lauer, 2003; Vetsch and Randall, 2004). Research comparing different tillage types and timings effects on corn emergence rate, alfalfa regrowth, and silage yield are minimal in the semi-arid, irrigated conditions of the Intermountain West.

One of the main drivers of corn yield and quality is N. The amount of available N in the soil varies based on the previous crop and is often deficient for high N use crops. Fertilizer N recommendations for corn after alfalfa are lower than corn following corn because alfalfa adds N to the soil and has the ability to continue to add N as it decomposes through the corn's growing season. The Corn Belt states of Indiana, Iowa, Michigan, Minnesota, Ohio, Wisconsin, and Minnesota give an N credit to the soil based on the number of alfalfa plants that are present when the stand is terminated. A 168 kg ha^{-1} N credit is given when $\geq$ 43 plants m^{-2} are present, a credit of 112 kg N ha^{-1} when 22 to 32 plants m^{-2} are present, and a credit of 45 kg ha^{-1} N when 10 plants m^{-2} are present

(Rehm et al., 2006). These recommendations are different from those in the Intermountain West states of Utah and Idaho. Idaho gives a credit of 67 to 112 kg N ha^{-1} when a good alfalfa stand is present and when that stand is below 22 plants m^{-2} or the corn variety being planted has a lower relative maturity a credit of 33 to 90 kg N ha^{-1} is given (Brown et al., 2010). In Utah, the N credit is 112 kg N ha^{-1} (Topper et al., 2010). With a yield goal of 20.7 Mg ha^{-1} the N recommendation is 224 kg N ha^{-1} (Cardon et al., 2008). The average cost of N fertilizer has increased from US$0.25 kg^{-1} in 2000 to US$0.93 kg^{-1} in 2013 (USDA Economic Research Service, 2013). The price increase is largely due to the increase in fuel prices and increase in demand from developing countries like China and India (Huang, 2009). If the N credit can be increased to that of the Cornbelt states producers would save approximately US$52.00 ha^{-1}. The literature shows that most of the time within each system of NT and CT the decomposing alfalfa stand will supply enough N to maximize yields of the following corn crop saving producers US$104.00 ha^{-1}, but there are some exceptions. New studies need to be done in order to determine if the N credit given in the Utah/Idaho region of the Intermountain West needs to be updated to or near the ranges given in the Corn Belt states.

Although the total amount of N in the soil is important the most critical question is whether the amount and timing of N produced by each termination method is sufficient to optimize the silage yield and quality of the following corn crop. As stated above the literature shows that within each system of NT and CT most of the time the decomposing alfalfa stand will supply enough N to maximize yields of the following corn crop, but there are some exceptions. Information regarding what conditions will require fertilizer to optimize yield and/or quality need to be determined. Information regarding if corn in a ST system needs added fertilizer N to optimize quality and yield is not known.

Most of the research regarding comparisons between alfalfa termination methods, timings, and fertilizer rates rotating into corn silage have been done in the Midwest to Northeastern states where soil conditions, mean temperatures, and growing seasons are much different from the Intermountain West. Because of this, and the reasons stated above, more research is needed in this region comparing silage corn yield, quality, and its response to fertilizer N in the first-year after alfalfa based on termination method and timing.

Summary and Objectives

Alfalfa is the number one crop grown in Utah. Typical stands last between 3 to 5 years. When the stand density falls below the economic optimum it is commonly rotated to a high N using crop such as corn, wheat, or barley. The standard termination practice is to use a glyphosate containing herbicide and/or conventional tillage (deep ripping and disking in the fall or spring and a then a form of secondary tillage before planting). The development of glyphosate-resistant (Roundup Ready®) alfalfa eliminates glyphosate as a stand removal option. The common recommendation for an herbicide is now 2,4-D plus dicamba, which has more restrictions in regards to the timing of application and when subsequent harvesting, tilling, and planting can be done. Conservation tillage techniques such as no-till and strip-till are also becoming more popular in the Intermountain West. No-till because of its ability to leave residue on the soil surface decreasing the potential for erosion and decreasing fuel, equipment, and labor costs. Strip-till because of its ability to still till the soil and incorporate the residue similar to conventional till in the area where the seed will be placed but also leaving the plant residue on the soil surface in between the rows decreasing the potential for erosion while still decreasing fuel, equipment, and labor costs. These potential management changes (i.e. herbicide application timing, and different types and timing of tillage) have the potential to affect soil compaction, soil temperature, erosion, and alfalfa regrowth. These factors may impact the breakdown of alfalfa plants and the release of N into the soil that is then available to the subsequent corn crop, potentially affecting silage yield and quality.

The objectives of this research were to 1) determine the alfalfa control percentage, corn emergence rate index, penetration resistance of the soil, and corn silage yield, quality, and economic return of different combinations of tillage types and timings, herbicide timings, and N rates, 2) determine if first-year corn after alfalfa based on termination method and timing requires added fertilizer N to optimize quality, yield, and economic return, and if so, how much, and 3) determine if there are any interactions between tillage type and timing, herbicide timing, and N rate.

MATERIALS AND METHODS

This study was conducted at a site in Cornish and Cache Junction, Utah ($41^{o}59'$ N $111^{o}57'$ W) in 2012 and 2013 with a total of four sites over the two year period. Cornish had a loamy fine sand soil texture (Layton, Mixed, mesic Psammentic Haploxerolls) (Soil Survey Staff, 2014a, 2014b) in 2012 and a fine sandy loam texture (Kidman, Corase-loamy, mixed, superactive, mesic Calcic Haploxerolls) in 2013. Cache Junction had a silty clay loam soil texture (Trenton, Fine, mixed, superactive, mesic Typic Natrixerolls) in 2012 and 2013. The alfalfa fields had been in commercial production for five to seven years at the time they were terminated. Each experiment started in the fall of the last year the alfalfa stand was in production. Alfalfa plant population was determined by digging up alfalfa plants inside two 0.5-m^2 quadrats per replication at each site and counting the number of crowns. The experimental design was a randomized complete block in a split-split plot arrangement with four replications. The whole plots measured 3.0 m wide (4 rows) and 122.0 m long in 2012 and 146.3 m long in 2013. Each whole plot received one of five different combinations of tillage and tillage timings a minimum of 7 to 14 days after herbicide treatment following herbicide label guidelines [fall conventional tillage (FCT), spring conventional tillage (SCT), fall strip-till (FST), spring strip-till (SST), and no-till (NT)]. The FCT and SCT treatments were deep ripped to a depth of 45 cm on 45 cm centers with a seven shank Miskin (Miskin, Ucon, ID) Model S207 Ripper then disked to a depth of 15 cm using a Krause (Kuhn Krause, Inc., Hutchinson, KS) Model 5815W disk. Final seedbed preparation was done with a Brillion (Brillion Farm Equipment Landoll Corporation, Brillion, WI) roller harrow before planting in Cache

Junction or by lightly disking the area followed by a harrow in Cornish. Fall strip-till and SST treatments were tilled to a depth of 20 cm and a width of 25 cm using a two row Orthman (Orthman, Lexington, NE) 1 tRIPr Model 839-076 strip till implement. Corn seed was planted directly into the strip-tilled area without further seedbed preparation. The NT treatment received no tillage before planting. Subplots measured 3.0 m wide and 30.5 m long in 2012 and 36.6 m long in 2013, consisting of one of four 2,4-D LV6 (2-ethylhexyl ester of 2,4-dichlorophenoxyacetic acid) at 784 g a.e. ha^{-1}, plus dicamba (3,6-dichloro-2-methoxybenzoic acid) at 280 g a.e. ha^{-1}, plus non-ionic surfactant (NIS) at 0.25% NIS v/v herbicide application timings (fall, spring, in-crop, and control) at a spray volume of 140 L ha^{-1}. The fall timing was done when sufficient alfalfa regrowth occurred after the last alfalfa cutting (between 4 to 15 Oct. of each year). The spring timing was done approximately two weeks before the desired tilling date (28 Apr. 2012 and 24 Apr. 2013). The in-crop timing was sprayed when the corn was approximately at V2-V3 growth stage (8 and 15 June 2012 in Cornish and Cache Junction, respectively, and 17 June 2013 for both sites) simulating the practice of a farmer taking the spring cutting of alfalfa, planting corn immediately, and then controlling the alfalfa when it had sufficient leaf area to spray. The control timing was no herbicide application. Sub-subplots measured 3.0 m wide and 7.6 m long in 2012 and 9.2 m long in 2013 consisting of four nitrogen (N) rates (0, 56, 112, and 224 kg N ha^{-1}) that were applied broadcast in the form of liquid 32% Urea-ammonium nitrate (UAN) solution. Nitrogen was applied within seven days after planting and immediately sprinkled with approximately 25 mm of irrigation water to incorporate the fertilizer.

Before each herbicide treatment was applied, alfalfa regrowth height and biomass measurements were taken (Table 3). Height measurements were taken by averaging the height of all of the alfalfa plants in two 0.5-m^2 areas per replication. Biomass was determined by hand clipping those same plants, weighing them, drying them in a forced-air oven at 60°C, and weighing them again to determine dry matter yield.

Dekalb (Monsanto, St. Louis, MI) corn hybrid DKC 55-24 was planted with a four-row Monosem (Monosem Inc., Edwardsville, KS) no-till NG Plus 4 precision vacuum planter 5-cm deep in 76-cm rows at 93,860 seeds ha^{-1}. Cornish was planted on 12 May 2012 and 24 May 2013. Cache Junction was planted on 21 May 2012 and 17 May 2013. Acetochlor (2-chloro-2′-methyl-6′-ethyl-N-ethoxymethylacetanilide) and Paraquat (1,1′dimethyl-4,4′-bipyridinium dichloride) were applied pre-emergent to control weeds and to chemically mow the existing alfalfa so plots were void of green vegetation at the time of planting.

Penetration resistance was measured 6 to 7 weeks after planting and 4 days after each site was evenly watered. The measurement was taken in each main plot using a Rimik (Rimik, Toowomba, QLD, Australia) CP40II Cone Penetrometer with a cone size of 130 mm^2. Three insertions were made per main plot at a rate of 0.2 to 4 m min^{-1} with readings every 1 cm to a depth of 60 cm. Due to equipment problems, only data from 2013 will be presented in this paper.

Emergence rate was calculated by marking 5.3 m of each 224 kg N ha^{-1} sub-subplot within each herbicide timing subplot before corn started emerging. Once corn began to emerge, plant counts were taken each day until germination was considered complete. The emergence rate index (ERI) was then calculated by the following equation

(Erbach, 1982). As the ERI increases the number of days from planting to full emergence is decreasing.

$$ERI = \sum_{n=first}^{last} \frac{\%n - \%(n-1)}{n}$$

Where:

N = number of days after planting

First = number of days after planting when the first plant emerged

Last = number of days after planting when emergence is complete

%n = the percentage of plants emerged on day n

%(n-1) = percentage of plants emerged on day n-1

Alfalfa control measurements were taken by determining the alfalfa density and biomass remaining in each sub-subplot before corn harvest. Alfalfa stem counts were taken by counting the number of stems in a 0.11-m^2 quadrat in two locations per plot and then averaged or by counting the number of stems in the entire subplot (5.2 m^2 in 2012 and 6.27 m^2 in 2013). Biomass was taken by hand clipping alfalfa in two 0.5 m^2 quadrats or the entire subplot, weighing them, drying them in a forced-air oven at 60°C, and weighing them again to determine dry matter yield.

The center two rows of each sub-subplot were harvested with a two row Gehl (Gehl, West Bend, WI) Model 865 pull behind corn silage chopper between 25 Sept. and 9 Oct. 2012 and 1 and 7 Oct.2013. The silage was blown into a weigh bin mounted on load cells that were connected to a Transcell Technology (Transcell Technology INC, Buffalo Grov, IL) TI-500 SS digital weight indicator that measured silage weight for each plot. After the weight measurement was recorded, the corn silage was dumped and a 1-kg subsample was collected to determine moisture and quality. Each sample was weighed, dried at 60°C in a forced air oven for 7 days, and weighed again to determine dry matter yield. The samples were ground through a Wiley mill (Thomas Scientific, Sweetesboro, NJ) Model 3 fitted with a 2-mm screen, repeatedly passed through a splitter until reduced to 50 g, and ground through a cyclone mill (Udy Corporation, Fort Collins, CO) with a 1-mm screen. Samples were scanned using a NIRSystems 6500 (NIRSystems, Silver Springs, MD) Near-Infrared Reflectance Spectrophotometer (NIRS) following Martin et al. (1989) then the 2012 unfermented corn silage equation developed by the near-infrared reflectance spectroscopy consortium (NIRSC) was used to determine the forage quality constituents of amylase neutral detergent fiber (aNDF), crude protein (CP), in vitro true dry matter digestibility at 48 hours (IVTDMD48), starch, and neutral detergent fiber digestibility at 48 hours (NDFD48). The statistical analyses of global H (GH) and neighborhood H (NH) were used to determine if the samples scanned fit well within the calibration set of the 2012 unfermented corn silage equation. All samples were below the 3.0 level of GH and the 1.2 level of NH showing that all samples qualified as good. Crude protein, aNDF, NDFD, NDFD48, starch, constants for fat and ash, and dry matter yield were used in the Milk 2006 worksheet developed at the University of Wisconsin to determine total dietary nutrients at maintenance (TDN-1x), net energy of lactation at 3x maintenance (NEL-3x), Milk Mg^{-1} (kg of milk Mg^{-1} corn silage), and Milk ha^{-1} (kg milk ha^{-1} corn silage) (Shaver, 2006; Shaver et al., 2006).

The economic return for silage corn was determined by subtracting tillage and herbicide costs from silage corn income. The price of corn silage (US$151.24 Mg^{-1} dry matter) was determined using the equation described in Feuz et al. (2012) using a hay price of US$149.73 Mg^{-1} (US$165 ton^{-1}) and dividing it by 33% to convert it to a 100% dry matter price. Tillage and herbicide application costs were determined using custom rates from Idaho (Patterson and Painter, 2011) due to the sites close proximity. No custom rates for strip-till were found for Utah or Idaho but were found in Nebraska (Wilson and Overturf, 2012). Custom rates in Idaho were determined to be approximately 42% more than Nebraska so the Nebraska custom strip-till price was increased by 42% for use in this economic analysis. Chemical costs were based on current market value and amount used per hectare (Intermountain Farmer's Association, personal communication, 2014).

Statistical Analysis

Penetration resistance was evaluated using the PROC MIXED procedure in SAS 9.4 (SAS Institute Inc, Cary, NC). Three insertions were taken per treatment and then averaged. Residual plots did not show violations of normality and constant variance assumptions. Penetration resistance was evaluated as a split-plot with two locations, four blocked replicates, tillage as the whole plot factor, and depth the subplot factor. Measurements were taken at the same level of herbicide and N rate so as to not become a confounding factor. Tillage, depth, and location were considered fixed effects and blocks were considered to be random effects. Since the two sites had different soil types, they were evaluated separately. Least square means for PR were calculated using the

LSMeans statement and the differences between them were determined using the simulate method to adjust for multiple comparisons.

Alfalfa biomass, average stem count-per-square-meter, ERI, and economic return were evaluated using the MIXED procedure in SAS 9.4 (SAS Institute Inc, Cary, NC). Log_{10} (x + 1) transformations were done for alfalfa biomass and average alfalfa stem count m^{-2} before analysis. The number one was added to avoid taking the log of zero. Residual plots did not show violations of normality and constant variance assumptions. Analysis was done using a split-plot with two years, two sites, four blocked replicates, tillage as the whole plot factor, and herbicide as the subplot factor. Samples were gathered at the sub-subplot level at the same N rate in order to not make N a confounding factor. Site, year, block, and tillage nested within block x site x year were considered random factors. Fixed factors were tillage, herbicide, and their interaction. Least square means were calculated for tillage, herbicide, and their interaction using the LSMeans statement and the differences between them were determined using the simulate method to adjust for multiple comparisons.

Covariate analysis using the PROC MIXED procedure in SAS 9.4 (SAS Institute Inc, Cary, NC) was used to evaluate dry matter yield and silage quality measurements (Littell et al., 1996). Measurements of CP, aNDF, starch, NDFD48, IVTDMD48, and TDN-1x, dry matter yield, and milk ha^{-1} were log_{10} (x) transformed before analysis. Residual plots did not show violations of normality and constant variance assumptions. Yield and quality measurements were analyzed as a split-split plot with two years, two sites, four blocked replicates, tillage as the whole plot factor, herbicide as the subplot factor, and N rate as the sub-subplot factor. The tillage by herbicide interaction was found to have a significant effect so N rate was covariate in the model to test if increasing N increased yield or quality measurements. Year, site, and block were considered random factors and tillage, herbicide and N rate were considered fixed factors. Since fertilizer trends differed by the tillage by herbicide interaction, separate analysis for each tillage by herbicide combination was performed. Linear and quadratic trends were tested and the trends that were not significant at the 0.05 level were removed from the model. Slopes that were not significantly different ($\alpha = 0.05$) from zero indicated that fertilizer did not affect the yield or quality measurements. Least square means for tillage by herbicide combination were calculated using the LSMeans statement and the differences between them were determined using the simulate method to adjust for multiple comparisons.

RESULTS AND DISCUSSION

Weather

Most of Utah's precipitation comes in the form of rain and snow in the cooler months of Sept. through May. The months of June through Aug. are normally hot and dry (Table 2). The Cornish and Cache Junction sites are approximately 19 km apart. A weather station that is within 11 km of both sites was used to collect weather data for the two years of this study (2012-2013) and compare years with the long term average of the area (1948-2013). Cornish and Cache Junction experienced moderate to severe drought conditions in the 2012 and 2013 growing years (i.e. 1 Oct. 2011 through 30 September 2012 is the 2012 growing year). In the cooler, rainy months of Sept. through May the total precipitation was 196.6 mm and 135.4 mm (averaging -17.2 and -22.4 mm month^{-1} below average), the hot, dry months of June through Aug. were 51.7 and 67.3mm (averaging -17.2 and -22.4 mm month $^{-1}$ below average), and the overall annual precipitation was 248.3 and 202.7 mm (averaging -20.7 and -16.9 mm month^{-1} below average) for 2012 and 2013, respectively. Irrigation was used to provide the needed water to prevent the plants from experiencing drought stress. The annual average air temperature for both years was within 1^{o}C with 2012 being 0.7^{o}C above and 2013 being 0.083^{o}C below the long term average. In the 2012 growing season, the average temperature of the fall months of Sept. through Nov. were equal to the long term average, the winter months of Dec. through Feb. were 2^{o}C higher, the spring months of Mar. through May were 1.7^{o}C higher, and the hot, growing months of June through Aug. were 0.96^{o}C below the long term average. In the 2013 growing season, the fall month's average temperature was 1.5^{o}C higher, the winter months were 3^{o}C below, the spring months were equal, and the hot, growing months were 1.4^{o}C higher than the long-term average.

Soil Characteristics

The fixed factors location, tillage, and depth were significant ($P < 0.05$), along with the location by depth and tillage by depth interaction for penetration resistance (PR). Because location was significant, most likely due to different soil types, each site was evaluated separately. In Cornish, tillage had an effect at depths of 2 to 26, 42, 43, and 48 to 52 cm (Table 4; Fig. 1). All other depths between these and below 52 cm down to the measured 60 cm were not affected by tillage treatments. Penetration resistance was similar between all tillage treatments when compared to NT at depths of 23 cm and below. The differences found at the depths of 17, 18, 23 to 26, 42, 43, and 48 to 52 cm were between FST and FCT, SCT, and/or SST and not NT. Similar to our findings Licht and Al-Kaisi, (2005) found that there were not significant PR differences in tillage when compared to NT in the top 10 cm, and that NT was greater than strip-till and chisel plow in the 10- to 20-cm depth, and no differences were found below 20 cm. The SCT treatment reduced PR compared to NT at all depths except for 17- to 18, 23- to 26, 42- to 43, and 48- to 52-cm where all tillage treatments were similar to NT. The SST treatment reduced PR below NT in the 3- to 13-cm depths. The NT and FST treatments were similar at all depths except for at 50 cm where FST > NT. From 19- to 26-cm deep FST and/or SST also had a greater PR than SCT showing that ST's ability to relieve compaction ends near its 20-cm depth of tillage. Penetration resistance was similar between the FCT and SCT treatments. However, when tillage was reduced to a strip-till system tillage timing was important. In those depths where tillage had a significant effect FST > SST in the 2- to 13 and 48- to 51-cm depths while the other depths FST = SST. This shows that as tillage intensity decreases the spring tillage timing has a greater ability to maintain a decrease in compaction.

In Cache Junction, tillage did not affect PR for the first 4 cm and from 42- to 60-cm deep (Table 5; Fig. 2). There was a difference in PR from 4- to 42-cm deep, which is approximately the depth of conventional tillage. This supports other studies that determined tillage reduces PR in the top 15 to 20 cm of the soil or to the depth of tillage (Vyn and Raimbult, 1993; Opoku et al., 1997; Vetsch and Randall, 2002; Janovicek et al., 2006; Vetsch et al., 2007). All tillage treatments significantly reduced PR in the 5- to 15-cm depths. Fall strip-till continued to reduce PR in the 16- and 17-cm depths, which is approximate to the 20-cm depth of tillage for strip-till. The FCT treatment also reduced PR significantly at the 16- and 27- to 40-cm depths while SCT reduced PR down to the approximate depth of tillage (42 cm). In addition to NT the SST and FST treatments were greater than SCT at the 24- to 40-cm depths. The PR of FST and SST were similar at all depths, but FCT > SCT from the 32- to 37-cm deep showing that conventional tillage timing can have an effect on PR as depth increases.

Root growth becomes restricted when PR exceeds 1.5 MPa (Unger and Kaspar, 1994). The Cornish NT treatment was below this point from 1 to 3 cm and above it from 4 to 60 cm with a range of 0.758 to 3.816 MPa. Tillage treatments were able to increase the depth to which PR was below 1.5 MPa to 1 to 40 cm, 1 to 32 cm, 1 to 12 cm, and 1 to 21 cm for FCT, SCT, FST, and SST, respectively. The Cache Junction NT treatment was below 1.5 MPa from 1 to 5 cm and again from 16 to 28 cm. Tillage treatments were able to increase the depth PR was below 1.5 MPa to 1 to 46 cm, 1 to 54 cm, 1 to 34 cm, and 1 to 34 cm for FCT, SCT, FST, and SST, respectively. When NT's PR decreased below 1.5 MPa again in the 16 to 28 cm depths it may have been what caused FST and/or SST to become similar to NT before ST's 20-cm depth of tillage.

These two studies partially support the finding of Vetsch et al. (2007) where it was determined that PR was similar across all tillage treatments in the top 8 cm and then NT was significantly higher to the depth of tillage. However, this study determined that PR was only similar across tillage treatments in the top 1 cm and 3 cm at Cornish and Cache Junction, respectively. Our results show that compaction that was relieved by tillage in the top few centimeters may have been re-compacted to that of NT by the tillage equipment or that compaction of the NT areas did not begin until below the 1- or 3-cm depths at Cornish and Cache Junction, respectively whereas Vetsch et al. (2007) experienced this in the first 8 cm. Both sites did not have PR differences due to tillage past 52 cm. Tillage was able to decrease PR down to the depth of tillage for both tillage systems at Cache Junction where in Cornish the differences due to tillage were minimal and sporadic after 26 cm. Both sites showed that as depth increased tillage had a smaller effect on PR. This finding is supported by Erbach et al. (1992), Vyn and Raimbault (1993), Unger and Jones (1998). The FST treatment never reduced PR in Cornish but it did down to 17 cm in Cache Junction. Tillage timing was important for strip-till in Cornish but not for conventional tillage in Cache Junction and for different depths at each site. Many of these results may be explained by the difference in soil characteristics for each site. The silty clay loam soil of Cache Junction responded better to tillage treatment attempts to decrease compaction as evidenced by the lower PR of each tillage system up to each depth of tillage compared to NT. The sandy clay soil of Cornish still had lower PR due to tillage compared to NT, however the differences were fewer, less distinct, and more sporadic throughout the 60-cm depth measured. These results show that tillage's ability to decrease soil PR may be greater in fine-textured soils and lower in coarse-textured soils.

Emergence

In 2012, both sites experienced a warmer winter (+2.2^{o}C) and spring (+1.7^{o}C) than average. In 2013, the winter was colder (-3^{o}C) than average followed by an average spring. Both growing seasons were hot and dry, which may have impacted germination rate. Irrigation had to be used carefully to minimize crusting, which inhibits germination. The average air temperature from planting to complete germination was 15^{o}C. In 2012, the number of days from planting to first emergence at Cache Junction was two days more than at Cornish. This was most likely because the average temperature from planting to first emergence for Cornish was 2^{o}C higher. In 2013, the average temperature for both sites from their planting date to the average first emergence day was similar resulting in the same number of days from planting to first emergence. In both years at Cornish, the control and in-crop herbicide timings in NT and the fall, in-crop, and control herbicide timings in FST experienced, on average, a one day delay in emergence compared to the other treatment combinations. There was no delay at Cache Junction in emergence for any treatment compared to the others, either year. This supports previous findings that in a warm year, a coarse-textured soil will show greater differences in emergence compared to a fine-textured soil (Beyaert et al., 2002). This also supports the findings of another study where emergence was delayed by two days in NT compared to a CT system that included fall and spring tillage (Hayhoe et al., 1993; Moncrief et al., 1991). However, in our study the spring and fall herbicide timing combined with NT treatments, and the spring herbicide timing combined with FST treatment, did not cause a delay in germination. This is most likely due to their ability to decrease the amount of residue on the soil surface at the right time with herbicides enabling enough solar radiation to be absorbed, thereby resulting in similar germination rates as conventionally tilled treatments.

Tillage type and timing and herbicide timing had a significant effect on corn emergence rate index (ERI). There was no significant interaction between tillage type and timing and herbicide timing (Table 6, 7). Spring conventional tillage, FCT, and SST had a higher ERI than FST and NT. The lower ERI of FST and NT may have been due to their higher PR. This higher PR may have reduced the quality of the seed bed and the soil's ability to absorb solar radiation, thereby decreasing the temperature of the soil and slowing down emergence of the corn. The fall or spring timing of conventional tillage did not significantly affect ERI. The SST treatment had a higher ERI than FST showing that in a strip-till system tillage timing is important and that to obtain the best emergence rate, strip-tilling should be done in the spring. This is supported by a study by Beyaert et al. (2002) who determined that conventional till and strip-till can have similar soil temperatures resulting in similar emergence rates. The ERI was highest under the fall and spring herbicide timings. The ERI in the spring herbicide timing treatment was higher than the control and in-crop timing. This shows that ERI is maximized when herbicide application is done before tilling and planting, which may be due to those timings ability to remove residue from the soil surface that is reflecting solar radiation. In contrast to this, a study by Buhler and Mercurio (1988) determined that a fall herbicide timing led to warmer soil and a higher emergence rate compared to a spring herbicide timing, and is supported by Smith et al. (1992) who determined that in three of four years, the fall herbicide timing in a NT system at the late planting date was better than spring because, the spring herbicide timing delayed emergence and lowered grain yields. However, in their CT treatment there was no difference between the fall and spring herbicide timings effect on emergence and yield. Our finding that spring and fall herbicide timing are similar may be because our spring herbicide treatment was done early in the spring, thereby decreasing plant residue on the surface similar to that of the fall herbicide timing, whereas the herbicide timing for Smith et al. (1992) was immediately before planting. Spraying the alfalfa early terminates the alfalfa before it shades more of the soil surface, thereby increasing the amount of time and area of the soil that can absorb solar radiation.

Alfalfa residue covering the surface can reflect solar radiation and insulate the soil, and is probably the reason that the NT treatments had lower ERI than the FCT, SCT, and SST treatments. Both timings of conventional tillage completely removed plant residue from the surface allowing the soil to absorb all of the solar radiation available. It has been shown that if a 20- to 30-cm area has all of the residue removed (such as in ST) soil temperatures and emergence can be similar to that of CT (Shinners et al., 1994) This study supports that finding since the SST treatment’s emergence rate was similar to that of the FCT and SCT treatments. However, the FST treatment’s emergence rate was lower, which may have been because FST had weeds and alfalfa plants begin to grow in the residue free area in the early spring that reflected solar radiation and insulated the soil, thereby lowering the ERI. The alfalfa residue left on the soil surface during emergence in the in-crop and control herbicide timing treatments may have also been the reason for their lower ERI compared to the spring herbicide timing treatment. The ERI of the fall herbicide timing may have been similar to the spring herbicide timing because, they both lowered the amount of residue on the soil surface, and to the in-crop and control herbicide timings, because weeds and alfalfa began to fill in the bare soil areas in the spring, thereby reflecting solar radiation, and causing ERI to be between the spring, and in-crop and control herbicide timings. In practicality, there appeared to be very little difference between the ERI of the different treatments which is supported by Licht and Al-Kaisi (2005) who determined that ERI differences between different tillage systems are largest when temperatures are lower, and when they are higher (as our temperatures were) there is little difference in crop emergence rates.

Alfalfa Termination

There was a significant herbicide by tillage interaction (Table 6) when measuring alfalfa biomass. All treatments decreased alfalfa biomass (Table 8) when compared to NT plus control herbicide timing treatment (0% control). Tillage only (FCT, SCT, FST, SST with no herbicide timing) controlled 27% to 54% of the alfalfa biomass. Fall and spring conventional tillage alone controlled 50% and 54% of the alfalfa, respectively, while the FST and SST treatments controlled 28% and 32%, respectively. This coincides with the fact that strip-till tills about 26% of the 76-cm row spacing. Fall and spring tillage timings performed equally well in controlling alfalfa regrowth. All herbicide-only (fall, spring, and in-crop herbicide timings in NT) treatments had lower alfalfa biomass yields compared to the tillage only treatments. This differed from a study by Bullied et al. (1999) where it was determined that tillage reduced alfalfa biomass the same amount as the best herbicide treatments. The difference may be due to their tillage treatments consisting of two passes with a rototiller, and this research using a single pass of a ripper, then a disk, then a roller harrow, for seedbed preparation. A study by Moomaw and Martin (1976) demonstrated that 2,4-D plus dicamba can be as effective as moldboard plowing, supporting this study that determined herbicide treatments controlled alfalfa better than plowing alone when using less intensive tillage practices. However, a study by Moyer et al. (2003) showed that a double disk treatment in the spring can control alfalfa equal to that of moldboard plowing in the fall. This shows that disking a field twice is more effective at controlling alfalfa than ripping and disking once. The NT plus fall herbicide timing treatment reduced alfalfa biomass to 75 kg ha^{-1} (98.1% control). The NT plus in-crop or spring herbicide timing treatments controlled alfalfa biomass down to 27 kg ha^{-1} (99.3 % control) and 23 kg ha^{-1} (99.4% control), respectively. Herbicide-only and tillage plus herbicide treatments decreased alfalfa biomass more than tillage alone with alfalfa biomass yields ranging from 75 kg ha^{-1} (98.1% control) for the NT plus fall herbicide timing treatment down to 3 kg ha^{-1} (99.9% control) for the SCT plus spring herbicide timing treatment. Malhi et al. (2007) determined that a combination of herbicide plus tillage is needed to provide the best control of alfalfa biomass, but this study also found that herbicides alone can control alfalfa as well as when less intense tillage systems are combined with an herbicide application.

Herbicide timing is important when combined with tillage. Studies by Bullied et al. (1999), Malhi et al. (2007), and Moomaw and Martin (1976) show that alfalfa stands were better controlled by herbicides when applied in the spring compared to the fall. This research supports those findings except in a few instances. The lowest alfalfa biomasses in this study were achieved when the herbicide timing was applied before tillage and during the same season (SCT plus spring herbicide timing; FCT plus fall herbicide timing). When the herbicide timing was after or in a different season than the tillage treatment, alfalfa biomass increased. For example in the FCT treatment, the alfalfa biomass yield for the fall herbicide timing was 6 kg ha^{-1}, but increased to 24 kg ha^{-1} and 45 kg ha^{-1} in the in-crop and spring herbicide timings, respectively. These in-crop and spring herbicide timings combined with FCT may have yielded more because the FCT treatment alone only controls around 51.9% of the alfalfa biomass. The alfalfa that survived may have still been buried, or not yet recovered and actively growing again after the FCT by the time it was sprayed the following season. The fact that the in-crop herbicide timing had a lower biomass than the spring herbicide timing when combined with FCT may have been because more of the alfalfa had recovered and was actively growing when the in-crop herbicide timing was applied compared to the spring herbicide timing.

The SCT plus spring herbicide timing treatment achieved the lowest alfalfa biomass. Even though the fall herbicide timing was done before SCT it still had a higher alfalfa biomass, demonstrating the importance of alfalfa biomass being controlled best when herbicide application is done before tillage and during the same season. Before tillage operations there are many stems leading to a large root, whereas after tillage that large root is broken up into many small roots that have less stems than the original root increasing the amount of leaves that need to be contacted by the herbicide to kill all of the roots. This may be why alfalfa biomass is better controlled when the herbicide is sprayed before tillage is done. It may be important to spray and till in the same season because the plants that the herbicide treatment does not kill but only weakens are less likely to survive when tillage occurs before the plant can recover. When combined with SCT, the in-crop herbicide timing had a higher alfalfa biomass than fall and spring herbicide timings most likely due to the fact that the surviving plants had not all emerged from under the soil or did not have sufficient regrowth for the herbicide to make contact with the leaf tissue attached to each root at the time of herbicide application.

The fall, spring, in-crop, and control herbicide timings when combined with FST or SST were similar in the amount of alfalfa biomass left uncontrolled showing that tillage timing did not make a difference in a strip-till system. Within FST, the alfalfa biomass was similar in the in-crop and spring herbicide timing, and the fall and in-crop herbicide timing with the fall herbicide timing yielding more alfalfa than the spring herbicide timing. Within SST, the fall, spring, and in-crop herbicide timings alfalfa yields were similar. The spring herbicide timing always controlled the alfalfa biomass the best regardless whether strip-tilling was done in the fall or spring, which is different from conventional tillage where fall is the best herbicide timing for the FCT treatment and the spring herbicide timing is the best for the SCT treatment. This may be because strip-till controls nearly all of the alfalfa in the area it tills (26%) leaving the residue in the untilled area on top of the soil, undisturbed so little to none of the surviving alfalfa is buried and protected from the spring herbicide timing and a majority of the roots and stems stay intact and not separated into many pieces. Whereas the FCT treatment buries all of the residue, thereby protecting some of the surviving alfalfa plants from the spring herbicide application and increasing the number of roots and stems that need to be contacted by the herbicide due to the dividing up of the roots and stems into many pieces by the conventional tillage. In the NT treatment, the control herbicide timing yielded the most alfalfa followed by the fall, spring, and in-crop herbicide timings that equally controlled the alfalfa.

The herbicide by tillage interaction was also significant for average alfalfa stem count-per-meter squared (Table 6). The stem count results were fairly similar to that of alfalfa biomass with a few exceptions (Table 8). All treatments decreased alfalfa stem count compared to the NT plus control herbicide timing treatment (251.2 stems m^{-2}, 0% control). Tillage only treatments had higher stem counts than herbicide only and herbicide plus tillage treatments. There was no statistical difference between the types or timings of tillage without an herbicide application. The only practical difference between tillage timing may have been in strip-till where the FST treatment only treatment had 214.5 stems m^{-2} (15% control) remaining opposed to 160 stems $^{-2}$ (36% control) in the SST only treatment. The similarity of the stem counts among tillage treatments with no herbicide application was greater than with the alfalfa biomass. The number of stems-per-square meter remaining in the fall were 214.5, 160.0, 169.3, and 156.8 (15%, 36%, 33%, and 38% control) and the alfalfa biomass control was 28%, 32%, 50%, and 54% for FST, SST, FCT, and SCT, respectively with no herbicide application. The difference between the strip-till and conventional till systems, on average, were 22% for alfalfa biomass control whereas there is very little difference between stem count control percentages, not including the FST treatment. This may be because the amount of alfalfa that survives conventional tillage and strip-tillage without herbicide application is similar, but the alfalfa that survives conventional tillage may take longer to recover and begin growing back resulting in a lower biomass than the alfalfa that survives under strip-till.

When herbicides are used alone or in combination with tillage they result in similar stem counts that range from 11.2 stems m^{-2} in the SCT plus IC herbicide timing treatment to 1.5 stems m^{-2} in the SCT plus spring herbicide timing treatment. The fall, spring, and in-crop herbicide only treatments were statistically equal to one another. When looking at the amount of stems-per-square meter remaining compared to alfalfa biomass in regards to tillage type and timing there are a few differences. Fall strip-till and NT controlled the alfalfa stem count similarly to the way they controlled alfalfa biomass when combined with the different herbicide timings. The fall, spring, and in-crop timings controlled the stem count similarly under FCT whereas the fall and in-crop herbicide timings controlled alfalfa biomass the most. This may be because the fall and in-crop herbicide timings damaged the alfalfa more than the spring herbicide timing resulting in the same number of stems being able to produce a higher biomass. Within the SCT treatment, the fall and spring herbicide timing reduced the stem count similarly as opposed to where the spring treatment reduced the alfalfa biomass more than the fall timing. In the SST system, spring and fall herbicide timings were similar with the spring timing better controlling stem counts than the in-crop timing, which is different from alfalfa biomass where all three timings were equal. This supports the earlier theory that herbicide application is best done before tillage operations. In the instances where fall, spring, and/or in-crop herbicide timings were equally as effective at lowering the stem count, but then the fall timing produced a higher alfalfa biomass this may have occurred because the surviving alfalfa of the fall timing recovered and started growing again in the spring and the spring and in-crop herbicide timing’s survivors did not recover and start growing again until later in the season giving the fall herbicide timing more time for the alfalfa to recover and grow, thereby producing more biomass (Bullied et al., 1999).

Yield

Dry matter yields were found to be significantly affected by the interaction between tillage types and timings and herbicide timings (Table 6). Linear regression was performed for each tillage by herbicide timing combination against increasing N fertilizer rate to determine if the slopes of each combination were different from one another and if they were different from a slope of zero. Nitrogen rate was found to have a significant effect on yield supporting the findings of Sheaffer et al. (2006) (Table 10). Silage yields ranged from 23.9 Mg ha^{-1} in the SCT plus fall herbicide timing treatment down to 7.3 Mg ha^{-1} in the NT plus control herbicide timing treatment (Table 9). As tillage intensity decreased and tillage and herbicide timing moved away from spring the differences in yield increased.

The highest yielding treatments were those combinations of FCT and SCT with herbicide applications done in the fall, spring, or in-crop and the FST, SST, and NT treatments combined with a fall or spring herbicide application. Out of these combinations the higher yielding ones were those that had the tillage or herbicide application done in the spring whereas the lower ones had both done in the fall. The next highest yielding combinations were the SCT plus control herbicide timing and the SST, FST, and NT treatments combined with the in-crop herbicide timing. Tillage type has been shown to affect growth rates at different stages of corn growth differently, but in the end yields can be the same as was true in this study as long as herbicides were applied in the fall or spring (Carter et al., 1991; Smith et al., 1992; Aflakpui et al., 1994; Beyaert et al., 2002). However, there are studies in which yields differ based on tillage. For example; NT yields were significantly less than conventional tillage in one of two years (Aflakpui et al., 1993) and conventional tillage equals strip-till and is greater than NT (Randall et al., 2001; Vetsch and Randall, 2004). Compaction of the soil measured by PR may have also had an effect on yield. When herbicides were applied in the spring the higher PR of the NT treated plots still yielded similarly to the other tillage treatments showing that even though PR may be higher in NT it can still yield similarly to tilled systems (Janovicek et al., 2006). The decrease in yield as herbicide timing was done in the fall, in-crop, or control in FST, SST, and NT may have partially been to higher PR in NT for the whole soil profile and for the depths lower than depth of tillage in strip-till compared to conventional tillage. The 2.5% (0.6 Mg) and 6% higher yield of the SCT plus fall herbicide timing treatment compared to the average of FST plus SST combined with the spring herbicide timing and NT plus spring herbicide timing yield, respectively may also be explained by the increase in depth of the conventional tillage treatments that are below the root restricting PR of 1.5 MPa.

The spring, fall, and in-crop herbicide timings alone or in combination with tillage had significantly higher yields than the control herbicide timing where tillage was the only method of alfalfa control except the SCT plus control herbicide timing where it was higher than FST and NT at the in-crop herbicide timing. There were differences between each tillage only system with SCT > FCT >SST > FST > NT. Malhi et al. (2007) also determined that tillage plus herbicides are needed to control the alfalfa and not affect the yields of the following crop. This differs from others studies where moldboard plowing, rototilling, and double disking were shown to control alfalfa sufficiently as to not affect yield (Moomaw and Martin, 1976; Smith et al., 1992; Bullied et al., 1999; Moyer et al., 2003). The difference may be due to the less intensive tillage practices in this study and the one of Malhi et al. (2007) demonstrating as tillage practices decrease in intensity the reliance on herbicides to sufficiently control alfalfa and other weeds so they do not decrease yield of the following crop increases.

When herbicides are used in the fall, spring, or in-crop tillage timing does not significantly affect yield. When tillage alone is used to control alfalfa the spring timing yields more than the fall timing. The fall, spring, and in-crop herbicide timings of the FCT and SCT systems yielded similarly. The fall and spring herbicide timings of the FST, SST, and NT systems yielded similarly and were greater than the in-crop herbicide timing. There was no difference between the yields of each tillage system when herbicides were applied in the spring. When herbicides were applied in the fall the yields of SCT were similar to FCT and SST but greater than FST and NT, which were similar to FCT and SST. Spring conventional tillage yields were similar to FCT and higher than SST, FST, and NT with SST yielding the same as FST but greater than NT at the in-crop herbicide timing.

Due to the potential of shading and competition for water and nutrients between the alfalfa and corn it is critical that > 90% of the alfalfa be controlled during the first three weeks after the corn is planted so its emergence, development, and yield are not reduced (Moomaw and Martin, 1976; Mercurio and Buhler, 1985). This probably explains most of the differences seen between tillage types and timings combined with different herbicide timings. Those combinations of tillage type and timing and herbicide timing that controlled alfalfa sufficiently through the critical period had optimal yields and those that did not control the alfalfa during the critical period had reduced yields. The fall and spring herbicide applications were able to sufficiently control the alfalfa during this critical time resulting in all of the tillage treatments when combined with the fall or spring herbicide timing to yield similarly. The in-crop timings within FST, SST, and NT allowed the alfalfa to compete with the corn during the critical time resulting in a decrease in yield. The in-crop application of 2,4-D plus dicamba may have also injured the corn to the point it was not able to recover enough to yield similarly to the fall and spring application timings. The fact that the in-crop herbicide timing of FCT and SCT did yield similarly to the fall and spring herbicide timings may have been because of their ability to control enough of the alfalfa with tillage operations through the critical period until herbicides were applied. The tillage treatments combined with the control herbicide timing may have had significantly lower yields than the herbicide only or herbicide plus tillage combinations because of their inability to adequately control the alfalfa as shown in their higher alfalfa biomass and stem counts. The SCT plus control herbicide timing treatment most likely yielded similarly to SST and FST at the in-crop herbicide timing because the conventional tillage controlled the alfalfa similarly during the critical weed free period. The FCT plus control herbicide timing treatment had similar alfalfa biomass and stem counts in the fall as the SCT plus control herbicide timing treatment, but the surviving alfalfa from conventionally tilling in the fall would have recovered and started growing in the spring competing with the corn during that critical period whereas conventionally tilling in the spring would have delayed alfalfa regrowth to later in the spring after the critical period had passed (Bullied et al., 1999). These reasons most likely also explain why FST > SST when combined with the control herbicide timing. The surviving alfalfa re-growing in the early spring in the FST plus control herbicide timing treatment may have resulted in as much competition to the corn as the NT plus control herbicide timing treatments, which may be why they yielded similarly. The FST plus control herbicide timing treatment and SST plus control herbicide timing treatment had lower yields compared to FCT and SCT at the control herbicide timing, which may have been because strip-tilling left a 56-cm untilled area where none of that alfalfa was controlled and competed with the corn reducing its yield.

Increasing N rate significantly increased yield in the NT and SST at the control herbicide timing. This supports others studies that found when alfalfa was sufficiently controlled that silage corn yield in a conventional tillage and NT system did not increase with additional fertilizer N (Rasse and Smucker, 1999; Basso and Ritchie, 2005; Yost et al., 2013a). However, other studies found that additional N did increase yield in conventional tillage and NT like we did in two treatment combinations (Soon and Clayton, 2003; Yost et al., 2012). These two treatments may have required additional N because they terminated 0% (NT plus control herbicide timing treatment) and 32% (SST plus control herbicide timing treatment) of the alfalfa biomass, which may have not been enough alfalfa decomposing and adding N to the soil. The SST and FST at the control herbicide timing (28% alfalfa biomass control) controlled alfalfa similarly, but the FST plus control herbicide timing treatment did not increase yield with additional N fertilizer.

This may be because the fall timing killed the alfalfa in the fall allowing it to begin to decay sooner adding sufficient N to the soil to provide for the corn whereas SST did not kill the alfalfa in the tillage area until spring delaying the decomposition of the alfalfa and subsequent addition of N to the soil until later in the growing season resulting in there not being sufficient N for the corn crop in the early growing stages so the N fertilizer made up for the lack of N in the beginning. This differs from studies by Aflakpui et al. (1994), Barnett (1990), Carter et al. (1991), Lawrence et al. (2008), and Rasse and Smucker (1999) that found termination in the fall and spring can provide sufficient N for first-year corn after alfalfa. However, those studies used conventional tillage or NT and herbicides that adequately terminated the alfalfa before planting. This may show that in order for the alfalfa to provide adequate N to the succeeding corn crop the alfalfa must be sufficiently terminated with a fall, spring, or in-crop herbicide treatment alone or combined with tillage in the fall or spring. Our study showed that when alfalfa is controlled greater than 95% and the alfalfa was controlled so as to not compete with the corn during the first three weeks after planting yields were optimized.

Quality

Tillage, herbicide, and the tillage by herbicide interaction had a significant effect on all quality measurements (Table 6). This differs from a study by Aflakpui et al. (1994) that determined that tillage system (conventional tillage verses NT) did not affect CP percentage, calcium, phosphorus, potassium, magnesium, total digestible nutrients, ADF, or NEL. Linear regression was ran for each tillage by herbicide combination against increasing N fertilizer rates to determine if the slopes of each combination were different from one another and if they were different from a slope of zero. Linear regression determined that with increasing N fertilizer rates ($P < 0.05$) there were differences between the combinations of tillage type and timing and herbicide timing for the measurements of CP and Milk ha^{-1}. There were also individual tillage by herbicide treatments whose slopes were greater than zero showing an increase in quality with increased N rates in the measurements of aNDF, IVTDMD48, NDFD48, NEL-3x, and Milk Mg^{-1}(Table 10). Other research also determined that N fertilization had an effect on CP but had only minimal effects on other quality measurements (Cox et al., 1993; Sheaffer et al., 2006; Lawrence et al. 2008).

The tillage only and herbicide only plots with the addition of the FST plus in-crop herbicide timing had the highest aNDF values. The aNDF was highest in the tillage only plots with the exception of SCT with NT = FST > SST > FCT. The SCT only treatment was similar to the FST plus in-crop, and the the fall, spring, and in-crop herbicide only treatments. Once the tillage and herbicide treatments were combined aNDF only varied by one percentage.

Fall and spring tillage resulted in similar aNDF values when herbicides were applied in the fall, spring, or in-crop if FCT or SCT was also used. When herbicides were applied in-crop or not at all, FST > SST. The fall, spring, and in-crop herbicide timings had similar aNDF values within FCT and SST while they varied for SCT, FST, and NT. The fall, spring, and in-crop herbicide timings resulted in fairly similar aNDF values regardless of tillage type and timing. Increasing N rate significantly decreased aNDF in the NT plus control and SST plus control treatments.

The tillage by herbicide combinations of SCT, FCT, and SST combined with the fall, spring, or in-crop herbicide timings along with NT and FST combined with fall or spring herbicide timings had the highest starch values followed by combinations of NT and FST with the in-crop herbicide timing and SCT with the control herbicide timing. The remaining tillage only treatments were significantly lower than all other treatments with FCT > SST > NT = FST. Within each tillage system the fall, spring, and in-crop herbicide timings resulted in similar values of starch except for FST where the in-crop herbicide timing was significantly lower than the fall and spring herbicide timing. The fall and spring herbicide timings had similar starch values across all tillage types and timings while the in-crop herbicide timing varied more with SCT = FCT = SST, SST = NT, and NT = FST. Tillage timing was significant in the in-crop and control herbicide timings with SCT > FCT. No tillage by herbicide combinations significantly increased in starch with increasing N rate.

The FST and NT treatments combined with no herbicide had significantly higher CP values than all other tillage by herbicide combinations. In general, the tillage combinations that contained the control and in-crop herbicide timings had the highest CP followed by the tillage treatments combined with the fall and spring herbicide timings. Within the NT and FST treatments the differences between herbicide timings were control > in-crop > fall = spring. The control = in-crop > fall = spring within the SST and FCT treatments, and within SCT all of the herbicide timings were similar. The CP value was similar in the spring herbicide timing across all tillage treatments. There were no differences between the FCT and SCT treatments when combined with the fall or spring herbicide timings. The control and in-crop herbicide timings were similar within FCT, SCT, and SST whereas control herbicide timing > in-crop herbicide timing in the FST and NT treatments. The FST and NT treatments were similar within each herbicide timing and the FCT, SST, and SCT treatments were similar within the spring, in-crop, and control herbicide timings but not in the fall herbicide timing. The fall and spring tillage timings of each tillage treatment were similar except for the in-crop and control herbicide timings for strip-till where FST > SST. As fertilizer rate increased CP increased for all tillage by herbicide combinations except for FCT plus the in-crop herbicide timing treatment ($P = 0.1063$) and SST plus the in-crop herbicide timing treatment ($P = 0.0762$).

The IVTDMD48 ranged from a high of 84.4 g kg^{-1} in the NT plus in-crop herbicide timing treatment to a low of 82.6 g kg^{-1} in the NT plus control herbicide timing treatment with a spread of 19 g kg^{-1}. In general, the fall and in-crop herbicide timings combined with each tillage treatment except the fall herbicide timing of FCT and SCT were higher than the spring and control herbicide timings combined with each tillage treatment. The fall and spring herbicide timings of each tillage treatment were similar within each tillage treatment and across FST, SST, and NT. The in-crop and control herbicide timings were similar for the FCT and SCT treatments, but they were different in the strip-till and NT treatments. The FCT, SCT, and FST at the in-crop herbicide timing = FCT, SCT, and SST at the control herbicide timing. Spring tillage was better than fall for strip-till in the in-crop and control herbicide timings. The SCT plus control herbicide timing treatment decreased in IVTDMD48 as fertilizer rate increased.

The combinations with the highest NDFD48 values were those treatment combinations containing the control herbicide timing except for SCT and the in-crop herbicide timing of NT and FST. All other combinations were lower and within 31.9 g kg^{-1} of one another with the NT, FST, and SST at the fall herbicide timing, the FCT and SST at the in-crop herbicide timing, and the SCT at the control herbicide timing being next. The lower values were the FCT, SCT, and SST at the fall and spring herbicide timing along with the NT and FST at the spring herbicide timing. The fall and spring herbicide timings were the same within FCT, SCT, and SST, and same between FCT and SCT along with the in-crop herbicide timing. The control and in-crop herbicide timings were different within all tillage types. Each herbicide timing was similar between FST and NT but different from each other with control > in-crop > fall > spring. No-till and FST were similar within each herbicide timing, but not across them. At the spring and control herbicide timings NT = FST = SST. Tillage timing is important for conventional tillage at the control herbicide timing and FST and SST at the in-crop herbicide timing where FCT > SCT and FST > SST. The SCT plus control herbicide timing treatment decreased NDFD48 significantly as N fertilizer rate increased.

The TDN-1x values ranged from a high of 673.1 g kg^{-1} in the SST plus control herbicide timing treatment down to 651.8 g kg^{-1} in the SCT plus spring herbicide timing treatment. The highest values were those combinations of FCT, FST, SST and NT at the in-crop and control herbicide timings. Next were the combinations of NT and ST at the fall herbicide timing and SCT at the control herbicide timing. The lower values were FCT and SCT at the fall, spring, and in-crop herbicide timings and FST, SST and NT at the spring herbicide timing. The fall and spring herbicide timings were similar within and across FCT and SCT and within and across FST and SST. The fall herbicide timing was greater than the spring herbicide timing in NT. The fall and spring herbicide timings of FCT, SCT, FST, and SST were similar. The in-crop and control herbicide timings were different within each tillage treatment except in SCT. The control herbicide timings were similar in the FCT, FST, and NT treatments. Tillage timing was only different in the control herbicide timing where FCT > SCT. The NT, FST, and SST treatments were similar within the fall and spring herbicide treatments.

The NEL-3x values ranged from 1.39 Mcal kg^{-1} in the NT plus in-crop herbicide timing treatment down to 1.35 Mcal kg^{-1} in the FST plus control herbicide timing treatment with only a difference of 0.04 Mcal kg^{-1}. The higher combinations were those of NT, FST, and SST at the in-crop herbicide timing and SST and FCT at the control herbicide timing. Next were FST, SST, and NT at the fall and spring herbicide timings and FCT and SCT at the in-crop herbicide timing then FCT and SCT at the fall and spring herbicide timings followed by NT and FST at the control herbicide timing. The fall and spring herbicide timings within and across SCT and FCT were similar. The fall and spring herbicide timing of FST, SST, and NT were similar within and across each tillage treatment along with the in-crop herbicide timing of FCT. The in-crop and control herbicide timing were different from each other within each tillage system except for in SCT. Tillage timing only made a difference in the control herbicide timing where SST > FST and FCT > SCT. The only treatment that NEL-3x increased with an increasing rate of N fertilizer was the FST plus spring herbicide timing treatment.

The amount of milk Mg^{-1} of dry matter (DM) ranged from 1441.4 kg of milk Mg^{-1} DM in the NT plus in-crop herbicide timing treatment to a low of 1388.5 kg of milk Mg^{-1} DM in the FST plus control herbicide timing treatment. The higher combinations were NT, FST, and SST at the in-crop herbicide timing and SST and FCT at the control herbicide timing followed by FST, SST, and NT at the fall and spring herbicide timings, the SCT at the control herbicide timing, and SCT and FCT at the in-crop herbicide timing. The lower combinations were NT and FST at the control herbicide timing and the FCT and SCT at the fall and spring herbicide timings. The fall and spring herbicide timings were similar within each tillage treatment and across the FCT, SCT, FST, SST, and NT except for the FST plus fall herbicide timing treatment was greater than the SST plus spring herbicide timing treatment. No-till is similar to FST and SST in the fall and spring herbicide timings and is similar to FST in the in-crop herbicide timing. Tillage timing was only significant at the control herbicide timing where SST > FST and FCT > SCT. Milk Mg^{-1} increased as N rates increased for the FST plus spring herbicide timing treatment.

The measurement of milk ha^{-1} had a high of 33.2 kg ha^{-1} in the FCT plus spring herbicide timing treatment and a low of 10.2 kg ha^{-1} in the NT plus control herbicide timing treatment. The treatments with the highest milk ha^{-1} value were FCT, SCT, and SST combinations containing the fall or spring herbicide timing and the FST and NT combinations containing the spring herbicide timing. The NT plus spring herbicide timing and SST plus fall herbicide timing treatments were lower than the FCT plus spring herbicide timing and SCT plus fall herbicide timing treatments. The next highest were the FST and NT treatments at the fall herbicide timing, all of the tillage treatments at the in-crop herbicide timing, and SCT at the control herbicide timing. The FST and NT treatments at the in-crop herbicide timing were similar to the SCT plus control herbicide timing, but lower than the others in this group. The FCT, SST, FST, and NT treatments at the control herbicide timings were lower than all of the other treatments with FCT >

SST > FST = NT. Tillage timing was only important in the control herbicide timing where SCT > FCT and SST > FST. Increasing N rates significantly increased milk ha^{-1} in the NT plus control herbicide timing and SST plus control herbicide timing.

The tillage by herbicide combinations that were the highest for starch reflected those of highest dry matter yield. This may have resulted because the herbicide only and tillage plus herbicide treatments sufficiently controlled the alfalfa during the critical weed free period so the corn was not competing with the alfalfa for light, water, and nutrients allowing it to grow and mature properly. These conditions most likely led to proper cob development and it has been shown that adequate ear development and grain fill have been correlated to increased concentrations of digestible energy such as starch and NEL-3x (Fairey, 1980). Those treatments with a middle value of starch may have resulted because the alfalfa was not fully controlled in the spring or came back and started competing with the corn too early decreasing cob development. Those with the lowest starch values were the control timings where alfalfa was only controlled by tillage allowing for a very high level of competition which most likely delayed growth, cob development and maturity resulting in a low starch value.

In general, the treatments that produced the lower DM yields had lower milk ha^{-1} and starch values but higher CP, aNDF, NDFD48, IVTDMD48, TDN-1x, NEL-3x, and Milk Mg^{-1}. The only exception was the NT plus control herbicide timing and FST plus control herbicide timing treatments. Their yield and starch value was much lower than all of the other treatments. They also had a high CP, aNDF, and NDFD48, but had the lowest IVTDMD48 and NEL-3x and was in the middle for TDN-1x and Milk Mg^{-1}. The IVTDMD48 and NEL-3x were most likely low for the same reason starch was explained to be low earlier. The higher CP, aNDF, and NDFD48 values for these two treatments may be high for similar reasons that the other lower yielding treatments were higher in all of the quality measurements except starch and milk ha^{-1}. The lower yielding treatments had the highest level of alfalfa competition which may have reduced plant growth, cob development, and maturity. The higher yielding treatments were those that sufficiently controlled the alfalfa in the fall with minimal regrowth in the spring or that had some form of tillage and/or herbicide that controlled the alfalfa in the early spring or killed it as it came back after tillage using an IC herbicide treatment minimizing the ability of the alfalfa to compete with the corn. This may have enabled the corn to grow, produce an ear, fill it, and mature more than the low yielding treatments. Research has shown that quality values decrease with increased plant maturity (Wiersma et al., 1993; Coors et al., 1997; Darby and Lauer, 2002; Di Marco et al., 2002), which may explain why most of the lower yielding treatments had higher CP, aNDF, NDFD48, IVTDMD48, TDN-1x, NEL-3x, and Milk Mg^{-1} values while the higher yielding treatments had lower values. One of the largest impacts on quality appeared to be whether or not the alfalfa was sufficiently controlled. Those treatments that relied entirely on tillage usually had the highest or lowest values and the largest differences between each other, but once herbicides with tillage or herbicides alone were used to control the alfalfa the differences between treatments were minimal.

Increased N rate only increased yield and quality parameters when tillage was combined with the control herbicide timing or the FST plus spring herbicide timing treatment. This may have resulted because these treatments did not terminate the alfalfa adequately or early enough for the alfalfa to decay enough in order to supply the needed amount of N to the soil for the corn like the other treatments did. The treatments that responded to increasing N rates for aNDF, IVTDMD48, and NDFD48 had significant negative slopes which may have occurred because the higher rates of N helped them grow and mature more than the lower N rates resulting in lower quality values due to increased maturity.

Economic Return

Economic return was significantly affected by tillage, herbicide, and the interaction between tillage and herbicide. Herbicide plus tillage and herbicide alone had higher returns than tillage alone. The FCT plus spring herbicide timing treatment had the highest return with US\$3,431.81 ha^{-1} and the FST plus control herbicide timing treatment had the lowest return with US\$1,196.63 ha^{-1}. The highest returning treatments were all tillage treatments combined with the spring herbicide timing plus the fall herbicide timing of the FCT and SCT treatments. Next were the FST, SST, and NT with fall herbicide timing treatments, averaging a decrease of US\$238.34 ha^{-1} compared to the economic return of the FCT plus spring herbicide timing treatment. Then the in-crop herbicide timings of each tillage and SCT plus control herbicide timing with SCT = FCT > SST = SCT plus control herbicide timing > NT = FST. These treatments returned, on average, US\$631.03 ha^{-1} less than the highest returning treatment. The lowest yielding treatments were the other tillage treatments combined with the control herbicide timing with FCT > SST > NT = FST returning, on average, US\$1,766.46 ha^{-1} less than the maximum returning treatment. Within FCT, SCT, and SST the herbicide timing of fall = spring > in-crop > control and within FST and NT spring > fall > in-crop > control. Tillage timing was important at the fall, in-crop, and control herbicide timings for ST because SST > FST. Spring conventional till > FCT at the control herbicide timing.

CONCLUSIONS

Alfalfa was best controlled when herbicides alone or herbicides plus tillage were used. The fall, spring, and in-crop herbicide timings across all tillage treatments reduced alfalfa stem count by ≥ 95% and alfalfa biomass by 98%. Tillage alone only reduced alfalfa biomass by < 54% and alfalfa stem count by 38%. When conventionally tilling, herbicide application is best when done before, and in the same season, as tillage. If strip-tilling in the fall, herbicides can be applied in the spring or in-crop. If strip-tilling in the spring or no-tilling, herbicides can be applied in the fall, spring, or in-crop for the best control of alfalfa regrowth.

Tillage reduced PR compared to NT down to or near the depth of tillage. Tillage also reduced PR greater and deeper in a fine-textured soil compared to a coarse-textured soil. The ERI was highest under FCT, SCT, and SST and when herbicides were applied in the fall or spring. Spring strip-till resulted in a higher ERI than FST, but tillage timing did not affect CT systems.

A grower is trying to get the best control of the alfalfa stand and optimize the yield, quality, and economics of first-year silage corn after alfalfa. To optimize yield, quality, and economic return, herbicides alone or in combination with tillage should be used to terminate the alfalfa stand when rotating into silage corn. All tillage types and timings can have similar yield, quality, and economic returns as long as herbicides are applied at the right timing to minimize alfalfa to corn competition. Herbicides can be applied in the fall or spring with FCT and SCT and in the spring with FST, SST, and NT.

If a dairy farmer would still like to use an in-crop herbicide timing to better control other weeds and the alfalfa or take the first cutting of alfalfa, plant the corn, and then use an in-crop herbicide timing to control the alfalfa they can expect a 3.2 (10%), 3.5 (11%), 5.4 (17%), 7.3 (23%), or 7.1 (23%) kg of milk ha^{-1} and a US$398, US$410, US$629, US$811, or US$842 ha^{-1} decrease for SCT, FCT, SST, FST, and NT, respectively compared to the average of fall and spring herbicide timing for FCT and SCT and spring herbicide timing for FST, SST, and NT. If an in-crop herbicide timing is chosen the tillage timing becomes important in ST because SST > FST. When alfalfa is adequately controlled increased N rates have minimal effects on first-year silage yield and quality showing that decaying alfalfa can provide sufficient N for first-year silage corn as long as herbicides or herbicides plus tillage are used to terminate the alfalfa stand and gives evidence that the N credit given to alfalfa when rotating into silage corn may need to be updated. In order to best control the alfalfa and optimize the yield, quality, and economic return for first-year silage corn herbicides should be applied in the spring or fall under conventional tillage and in the spring for ST and NT systems.

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APPENDIX. Tables and Graphs

Table 1. Monthly temperature, precipitation, and irrigation amounts for Cornish and Cache Junction for the water years of 2011-2012 and 2012-2013 with the difference from long term average for temperature and precipitation (1944-2014) in parenthesis.

	Cornish and Cache Junction				Cornish		Cache Junction	
	Temperature†		Precipitation		Irrigation		Irrigation	
Month	2011-2012‡	2012-2013	2011-2012	2012-2013	2011-2012	2012-2013	2011-2012	2012-2013
	°C		mm					
October	9.4 (0.7)	8.8 (0.1)	28.8 (-15)	42.3 (-2)	0	0	0	0
November	0.3 (-1.8)	4.2 (2.1)	40.6 (0.72)	22.6 (-17)	0	0	0	0
December	-5.5 (-1)	-2.9 (1.6)	2.8 (-33)	29.7 (-6)	0	0	0	0
January	-1.6 (4.1)	-12.7 (-7)	24.3 (-8)	22.3 (-10)	0	0	0	0
February	0.3 (3.6)	-7 (-3.7)	10.2 (-30)	7.1 (-33)	0	0	0	0
March	5.9 (2.9)	2.5 (-0.5)	21.5 (-23)	18 (-27)	0	0	0	0
April	10.3 (2.4)	7.4 (-0.5)	35.8 (-14)	33 (-17)	0	0	0	0
May	12.4 (0)	12.9 (0.5)	14.3 (-45)	37.4 (-22)	62.5	33.02	43.75	50.8
June	17.2 (0.3)	18.1 (1.2)	2.6 (-29)	0 (-31)	125	82.55	87.5	101.6
July	19.9 (-1)	22.7 (1.8)	12 (-9)	3.4 (-17)	187.5	170.18	187.5	152.4
August	18 (-2.2)	21.4 (1.2)	4.4 (-13)	0 (-18)	175	181.61	175	203.2
September	15.5 (0.7)	17 (2.2)	5.9 (-27)	33 (-0.4)	0	0	50	50.8
Annual	8.5 (0.7)	7.7 (-0.08)	203.2 (-248)	248.8 (-203)	550	467.36	543.75	558.8

† Weather data was obtained from the Utah Climate Center

‡ Water year starts in Oct. of the year before planting and goes until Sept. of the planting year.

§ A weather station central to both sites was used to obtain temperature and precipitation data.

Table 2. Alfalfa age, plant population, average regrowth height, and average biomass at each herbicide application timing at Cornish and Cache Junction in 2012 and 2013.

	Alfalfa							
		Plant	Regrowth height			Regrowth Biomass		
Site	Age	population	Fall	Spring	In-crop	Fall	Spring	In-crop
	years	plants m^{-2}	cm			g m^{-2}		
Cornish-2012	7	46	30	16	19	416.3	197.4	334.8
Cache Junction-2012	5	82	40	18	22	749.8	337.4	345.3
Cornish-2013	6	140	6	10	33	30.2	207.9	421.7
Cache Junction-2013	6	83	25	12	32	83.2	173.6	281.7

Table 3. Tillage type and timing's effect on Penetration Resistance (PR) by depth for Cornish 2013.

	Tillage type and timing				
Depth	NT†	FCT	SCT	FST	SST
cm	Mpa				
1	NS‡	NS	NS	NS	NS
2	1.0440a§	0.3662ab	0.1683b	0.9728a	0.3070ab
3	1.3920a	0.5233b	0.2971b	1.0634ab	0.4213b
4	1.5938a	0.7021b	0.4097b	1.1899ab	0.4990b
5	1.6349a	0.8220b	0.5138b	1.2250ab	0.5230b
6	1.6733a	0.8679b	0.5982b	1.2733ab	0.5117b
7	1.6756a	0.9214abc	0.6497bc	1.3307ab	0.5113c
8	1.7683a	0.9378bc	0.6459bc	1.3819ab	0.4983c
9	1.8112a	0.9746bc	0.6720bc	1.3314ab	0.4997c
10	1.7488a	0.9740abc	0.6887bc	1.3369ab	0.5330c
11	1.6909a	0.9952abc	0.7170bc	1.4048ab	0.6024c
12	1.5995a	1.0144ab	0.7511b	1.4819ab	0.6813b
13	1.5652a	1.0348ab	0.7540b	1.5168ab	0.7541b
14	1.5688a	1.0505ab	0.7190b	1.5393a	0.8208ab
15	1.5567a	1.0504ab	0.6741b	1.5724a	0.9021ab
16	1.4904a	1.0696ab	0.6804b	1.6470a	1.0033ab
17	1.4412ab	1.0978ab	0.6647b	1.6813a	1.1640ab
18	1.4234ab	1.0784ab	0.6342b	1.7178a	1.2797ab
19	1.4785a	1.0938ab	0.6285b	1.8179a	1.3957ab
20	1.5267a	1.0875ab	0.6542b	1.8408a	1.4749a
21	1.5295a	1.0673ab	0.6987b	1.8217a	1.4981ab
22	1.5502a	1.0911ab	0.7207b	1.7263a	1.5644a
23	1.5421ab	1.1332ab	0.7580b	1.7367a	1.5965a
24	1.5107ab	1.1900ab	0.8047b	1.7700a	1.6312a
25	1.5237ab	1.2080ab	0.8490b	1.7610a	1.6907a
26	1.5269ab	1.2708ab	0.9278b	1.7303a	1.7294a
27-41	NS	NS	NS	NS	NS
42	2.5377ab	2.3317ab	2.0983b	3.0563a	2.5343ab
43	2.6632ab	2.3585ab	2.2459b	3.1446a	2.5578ab
44-47	NS	NS	NS	NS	NS
48	2.9013ab	2.7673b	2.7677b	3.5773a	2.7657b
49	2.9615ab	2.9342ab	2.7735b	3.7213a	2.7964b
50	3.0460b	3.0518b	2.8363b	3.8697a	2.8636b
51	3.1820ab	3.1207ab	2.9287b	3.8899a	3.0215b
52	3.4097ab	3.1813ab	2.9799b	3.9028a	3.1215ab
53-60	NS	NS	NS	NS	NS

† NT, no-till; SCT, spring conventional tillage; SST, spring strip-till; FCT, fall conventional tillage; FST, fall strip-till.

‡ NS, nonsignificant at the 0.05 probability level.

§ Mean values with different letters in the same row are statistically different (P≤0.05).

¶ Penetration resistance was measured in the spring herbicide timing of each main tillage plot.

Table 4. Tillage type and timing's effect on Penetration Resistance (PR) by depth for Cache Junction 2013.

	Tillage type and timing				
Depth	NT†	FCT	SCT	FST	SST
cm			Mpa		
1-3	NS‡	NS	NS	NS	NS
4	1.1717a§	0.6052ab	0.4038b	0.6648ab	0.6093ab
5	1.3562a	0.6784b	0.4259b	0.7189b	0.5726b
6	1.5668a	0.7041b	0.4412b	0.7050b	0.5652b
7	1.7354a	0.7039b	0.4423b	0.7079b	0.5978b
8	1.7803a	0.7224b	0.4353b	0.7368b	0.6620b
9	1.7638a	0.7470b	0.4280b	0.7589b	0.7046b
10	1.6868a	0.7603b	0.4191b	0.7581b	0.7519b
11	1.6027a	0.7982b	0.4123b	0.7699b	0.7861b
12	1.5747a	0.8088b	0.4033b	0.7698b	0.8321b
13	1.5775a	0.8062b	0.4115b	0.7596b	0.8658b
14	1.5408a	0.8100b	0.4249b	0.7131b	0.8884b
15	1.5132a	0.8305b	0.4254b	0.6833b	0.8745b
16	1.4456a	0.8354b	0.4119b	0.6858b	0.8794ab
17	1.4169a	0.8418ab	0.3902b	0.7188b	0.9058ab
18	1.3595a	0.8242ab	0.3854b	0.8160ab	0.9018ab
19	1.3348a	0.7893ab	0.4022b	0.8763ab	0.9119ab
20	1.3324a	0.7457ab	0.4239b	0.9084ab	0.9696ab
21	1.3379a	0.7341ab	0.4457b	0.9329ab	1.0025ab
22	1.3277a	0.7542ab	0.4597b	0.9943ab	1.0392ab
23	1.3195a	0.7806ab	0.4379b	1.0433ab	1.0934a
24	1.2937a	0.8148ab	0.4441b	1.0941a	1.1151a
25	1.2733a	0.8140ab	0.4738b	1.1298a	1.1547a
26	1.3214a	0.7673ab	0.4971b	1.2178a	1.1519a
27	1.3726a	0.7604bc	0.5053c	1.2363ab	1.1172ab
28	1.4682a	0.7873bc	0.4880c	1.2188ab	1.1486ab
29	1.5024a	0.8593bc	0.4388c	1.2593ab	1.2145ab
30	1.6139a	0.9298bc	0.4055c	1.3559ab	1.2820ab
31	1.7327a	0.9801bc	0.3918c	1.4118ab	1.3447ab
32	1.7566a	0.9893b	0.3638c	1.4421ab	1.4247ab
33	1.8140a	1.0655b	0.3514c	1.4855ab	1.4388ab
34	1.8434a	1.1415b	0.4080c	1.4933ab	1.4747ab
35	1.8456a	1.1653b	0.4241c	1.5923ab	1.5327ab
36	1.8715a	1.1803b	0.4795c	1.6788ab	1.5965ab
37	1.8812a	1.2339b	0.5508c	1.6848ab	1.6160ab
38	1.9725a	1.2748b	0.6780c	1.6690ab	1.6719ab
39	1.9834a	1.3090bc	0.8325c	1.6758ab	1.7142ab
40	1.9629a	1.3377bc	1.0243c	1.7056ab	1.7156ab
41	1.8998a	1.3619ab	1.1178b	1.6943ab	1.7022ab
42	1.8808a	1.4070ab	1.2411b	1.6765ab	1.6193ab
43-60	NS	NS	NS	NS	NS

† NT, no-till; SCT, spring conventional tillage; SST, spring strip-till; FCT, fall conventional tillage; FST, fall strip-till.

‡ NS, nonsignificant at the 0.05 probability level.

§ Mean values with different letters in the same row are statistically different ($P \leq 0.05$).

¶ Penetration resistance was measured in the spring herbicide timing of each main tillage plot.

Table 5. Significance of F tests for the fixed effects of tillage (T), herbicide (H), tillage by herbicide interaction, and the fertilizer effect nested within each tillage by herbicide interaction for emergence rate index (ERI), alfalfa control measurements, corn silage quality and dry matter (DM) yield for Cornish and Cache Junction in 2012 and 2013.

Variable	T	H	T x H	Fertilizer(T x H)
	P > F			
ERI	0.0003	0.0122	0.2484	-
Alfalfa stem count	0.0029	<.0001	0.0003	-
Alfalfa biomass	0.0006	<.0001	<.0001	-
aNDF†	<.0001	<.0001	<.0001	0.4476
CP	<.0001	<.0001	<.0001	<.0001
IVTDMD48	0.0054	<.0001	<.0001	0.4930
Starch	<.0001	<.0001	<.0001	0.9418
TDN-1x	<.0001	<.0001	<.0001	0.8733
NDFD48	<.0001	<.0001	<.0001	0.2161
NEL-3x	0.0007	<.0001	<.0001	0.7359
Milk Mg^{-1}	<.0001	<.0001	<.0001	0.8455
Milk ha^{-1}	<.0001	<.0001	<.0001	0.0007
DM Yield	<.0001	<.0001	<.0001	0.0009
Economic Return‡	<.0001	<.0001	<.0001	-

† aNDF, Amylase neutral detergent fiber; CP, crude protein; IVTDMD48, in vitro true dry matter digestibility at 48 hours; TDN-1x, total dietary nutrients at maintenance; NDFD48, neutral detergent fiber digestibility at 48 hours; NEL-3x, net energy of lactation at 3x maintenance; DM, dry matter.

‡ Economic Return was only determined using tillage, herbicide, and their interaction due to fertilizer only having a small significant effect on two of the control treatments.
§ ERI, alfalfa stem count, and biomass were measured in 0 nitrogen (N) rate plots so the effect of increasing N at each tillage*herbicide combination was not determined.

Table 6. Emergence rate index (ERI) for corn following alfalfa as affected by tillage type and timing and herbicide timing in Cornish and Cache Junction in 2012 and 2013.

Tillage†	ERI	Herbicide§	ERI
SCT	7.66a‡	SP	7.60a
SST	7.64a	F	7.55ab
FCT	7.61a	C	7.49b
FST	7.38b	IC	7.49b
NT	7.37b		

† SCT, spring conventional tillage; SST, spring strip-till; FCT, fall conventional tillage; FST, fall strip-till; NT, no-till.

‡ Mean values with different letters in the same column are significantly different ($P \leq 0.05$).

§F, fall; SP, spring; IC, in-crop; C, control

Sites and years were considered random factors.

Table 7. Alfalfa stems count and biomass remaining after different tillage types and timings and herbicide application timings at Cornish and Cache Junction in 2012 and 2013.

		Alfalfa¶	
Tillage†	Herbicide‡	Stem count	Biomass
		stems m^{-2}	kg ha^{-1}
FCT	F	2.0ef§	5.7fg
FCT	SP	5.3bcde	47.2bcd
FCT	IC	6.2bcde	23.9bcdef
FCT	C	169.3a	1990.6a
SCT	F	3.3cdef	18.6bcdef
SCT	SP	1.5f	3.0g
SCT	IC	11.2b	51.3bc
SCT	C	156.8a	1828.6a
FST	F	9.7bc	49.1bcd
FST	SP	2.5def	11.2efg
FST	IC	6.3bcde	16.9bcdef
FST	C	214.5a	2873.3a
SST	F	5.3bcde	26.0bcdef
SST	SP	2.2ef	6.7efg
SST	IC	7.4bcd	13.5cdef
SST	C	160.0a	2718.4a
NT	F	10.3bc	74.9b
NT	SP	4.1bcdef	23.7bcdef
NT	IC	11.2b	27.2bcde
NT	C	251.2a	3969.5a

† FCT, fall conventional tillage; SCT, spring conventional tillage; FST, fall strip-till; SST, spring strip-till; NT, no-till

‡ F, fall; SP, spring; IC, in-crop; C, control

§ Mean values with different letters in the same column are statistically different ($P \leq 0.05$).

¶ Alfalfa stem count and biomass data shown are back transformed.

Sites and years were considered random factors.

Table 8. Amylase neutral detergent fiber (aNDF), crude protein (CP), in vitro true dry matter digestibility at 48 hours (IVTDMD48), starch, total dietary nutrients at maintenance (TDN-1x), neutral detergent fiber digestibility at 48 hours (NDFD48), net energy of lactation at 3x maintenance (NEL-3x), Milk Mg^{-1}, Milk ha^{-1}, dry matter (DM) yield, and economic return under different combinations of tillage types and timings and herbicide timings at Cornish and Cache Junction in 2012 and 2013.

Tillage†	Herbicide‡	aNDF	CP	IVTDMD48	Starch	TDN-1X	NDFD48	NEL-3X	Milk Mg^{-1}	Milk ha^{-1}	DM Yield	Economic Return¶
		g kg^{-1} DM					g kg^{-1} NDF	Mcal kg^{-1} DM	kg Mg^{-1} DM	kg ha^{-1}	Mg ha^{-1}	US$ ha^{-1}
FCT	F	441.1ghi§	69.0fghi	834.5efg	327.2ab	654.1gh	631.2jkl	1.37efg	1395.4hij	32.3ab	23.2abc	3327.44ab
FCT	SP	438.8ghi	68.5fghi	833.8fgh	328.8a	653h	628.3kl	1.369fg	1392.6ij	33.2a	23.9ab	3431.81a
FCT	IC	442.0ghi	70.4cdef	838.3cde	323.1ab	659.2ef	642.2ghi	1.377de	1410.2efg	29.3de	20.8bc	2969.59d
FCT	C	479.6c	72.1bc	837.6cdef	263.5e	666.7bc	663.8d	1.383bc	1423.4cd	21.7h	15.5g	2294.64g
SCT	F	436.6hi	69.6defgh	833.0ghi	329.8a	652.3h	624.9l	1.369fg	1391.9ij	33.2a	23.9a	3422.27a
SCT	SP	444.1fgh	69.2fghi	829.7hij	321.8abc	651.8h	625.5l	1.367g	1388.8j	32.4ab	23.5abc	3361.1ab
SCT	IC	433.6i	69.9defgh	838.7cde	331a	658.6ef	637.5ij	1.378d	1410.4efg	29.6bcde	21abc	2993.69d
SCT	C	452.5def	70.2cdefg	837.1cdefg	307.9bcd	659.8def	644.3fgh	1.378d	1410.4efg	26.2dfg	18.6d	2705e
FST	F	442.1ghi	68.3ghi	839.9bcd	322.6ab	662de	648.6fg	1.382cd	1418.1de	29.4cde	20.8bc	3063.05d
FST	SP	443.0fghi	68.6fghi	836.0cdefg	320.2abc	658.6ef	640hi	1.378d	1408.8efg	31.8abc	22.6abc	3341.92ab
FST	IC	460.9d	72.7b	839.6cd	292.7d	670ab	666.5cd	1.392a	1438.4ab	24.5fg	17.1ef	2530.7f
FST	C	543.3a	81.2a	828.8ij	138.4g	663.1cd	682.7a	1.355h	1388.5j	10.5j	7.6i	1196.63i
SST	F	433.9i	67.3i	841.1abc	333a	660.1def	642.1ghi	1.381cd	1414.3defg	31bcde	21.9abc	3231.24bc
SST	SP	434.9hi	68.1hi	838.0cdef	332.2a	657.1fg	635.4ijk	1.376def	1405.2fgh	31.7abc	22.7abc	3338.29ab
SST	IC	440.0ghi	70.3cdef	844.0ab	321.7abc	666.4bc	656.8e	1.39ab	1431.6bc	26.3de	18.4de	2709.1e
SST	C	498.3b	71.4bcde	837.0cdefg	237f	673.1a	677.5ab	1.39ab	1439.3ab	16.1i	11.2h	1698.64h
NT	F	448.0efg	69.4efgh	839.4cd	317.9abc	662.1de	651.2ef	1.381cd	1416.4def	29e	20.6c	3104.1cd
NT	SP	444.2fgh	69.2fghi	835.9defg	320.8abc	658.2f	640.3hi	1.377de	1406.9efgh	31.4bcd	22.4abc	3375.11ab
NT	IC	455.5def	71.6bcd	844.3a	302cd	671.9a	671.9bc	1.393a	1444.4a	24.3g	16.9f	2532.55f
NT	C	547.2a	80.9a	826.0j	145.1g	666.3bc	680.7a	1.364gh	1402.5ghi	10.2j	7.3i	1228.77i

† FCT, fall conventional tillage; SCT, spring conventional tillage; FST, fall strip-till; SST, spring strip-till; NT, no-till

‡ F, fall; SP, spring; IC, in-crop; C, control

§ Mean values with different letters in the same column are significantly different ($P \leq 0.05$).

¶ Economic return found using equation: Economic Return = Revenue (Price of silage * yield) - Expenses (cost of tillage treatment + herbicide treatment)

Sites and years were considered random factors.

†† The aNDF, CP, Milk ha^{-1}, and DM yield data shown are backtransformed.

Table 9. Linear regression equations for silage quality where the tillage by herbicide treatment was significantly affected by increased N rates (P < 0.05).

Tillage†	Herbicide‡	Intercept	Slope	Pr > |t|
			aNDF§	
NT	C	6.322†	-0.00021	0.026
SST	C	6.2298	-0.00023	0.014
			Crude Protein	
FCT	C	4.2163	0.00063	<.0001
FCT	F	4.2001	0.000339	0.0082
FCT	SP	4.19	0.000377	0.0037
FST	C	4.3485	0.00048	0.0002
FST	F	4.1808	0.000431	0.0008
FST	IC	4.246	0.000405	0.0016
FST	SP	4.1794	0.000493	0.0001
NT	C	4.3629	0.000299	0.02
NT	F	4.1911	0.000494	0.0001
NT	IC	4.2401	0.000314	0.0146
NT	SP	4.1896	0.00048	0.0002
SCT	C	4.2121	0.000398	0.002
SCT	F	4.2079	0.000354	0.0058
SCT	IC	4.2026	0.000444	0.0006
SCT	SP	4.2072	0.000296	0.021
SST	C	4.2057	0.000632	<.0001
SST	F	4.1533	0.00056	<.0001
SST	SP	4.1907	0.000304	0.0194
			IVTDMD48	
SCT	C	841.88	-0.05244	0.0053
			NDFD48	
SCT	C	650.25	-0.06508	0.0295
SST	C	683.77	-0.06946	0.0202
			NEL-3x	
FST	SP	1.3705	0.000073	0.0299
			Milk Mg^{-1}	
FST	SP	1397.94	0.1103	0.0416
			Milk ha^{-1}	
NT	C	2.1365	0.00189	<.0001
SST	C	2.6795	0.000989	0.003
			Dry Matter Yield	
NT	C	1.8064	0.001863	<.0001
SST	C	2.3207	0.000972	0.0034

† FCT, fall conventional tillage; SCT, spring conventional tillage; FST, fall strip-till; SST, spring strip-till; NT, no-till

‡ F, fall; SP, spring; IC, in-crop; C, control

§ aNDF, Amylase neutral detergent fiber; IVTDMD48, in vitro true dry matter digestibility at 48 hours; NDFD48, neutral detergent fiber digestibility at 48 hours; NEL-3x, net energy of lactation at 3x maintenance.

¶ The aNDF, CP, Milk ha^{-1} and dry matter yield values shown for slope and intercept are calculated from log transformed data and are not backtransformed.

Sites and years were considered random factors.

†† linear regression equation: y = quality or yield value = intercept + slope(fertilizer rate).

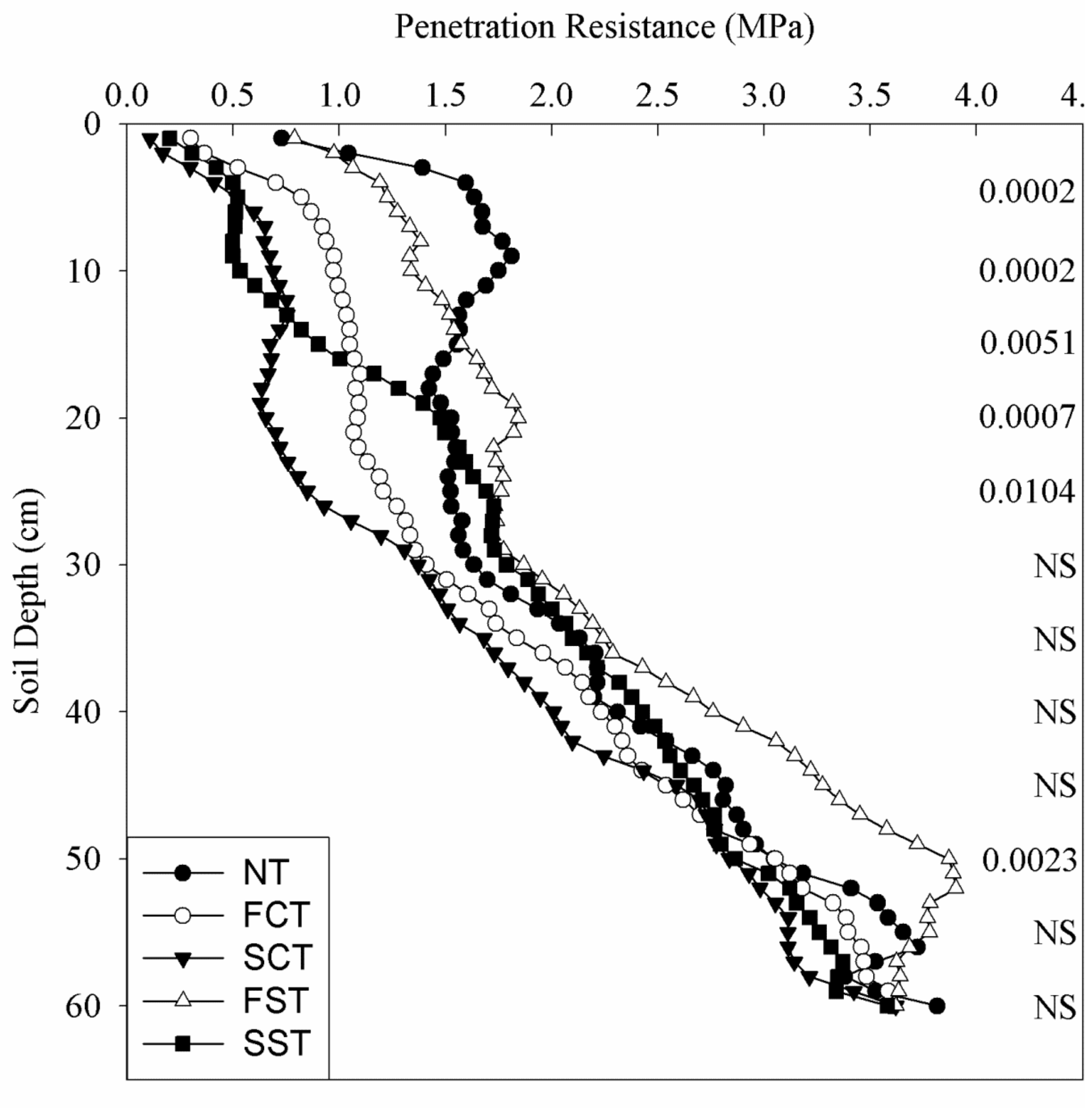

Fig. 1. Tillage effects on penetration resistance to a depth of 60 cm at Cornish, UT in 2013. Penetration resistance measurements were taken every cm but the P values shown on the right are only for every fifth cm. NT, no-till; FCT, fall conventional tillage; SCT, spring conventional tillage; FST, fall strip-till; SST, spring strip-till.

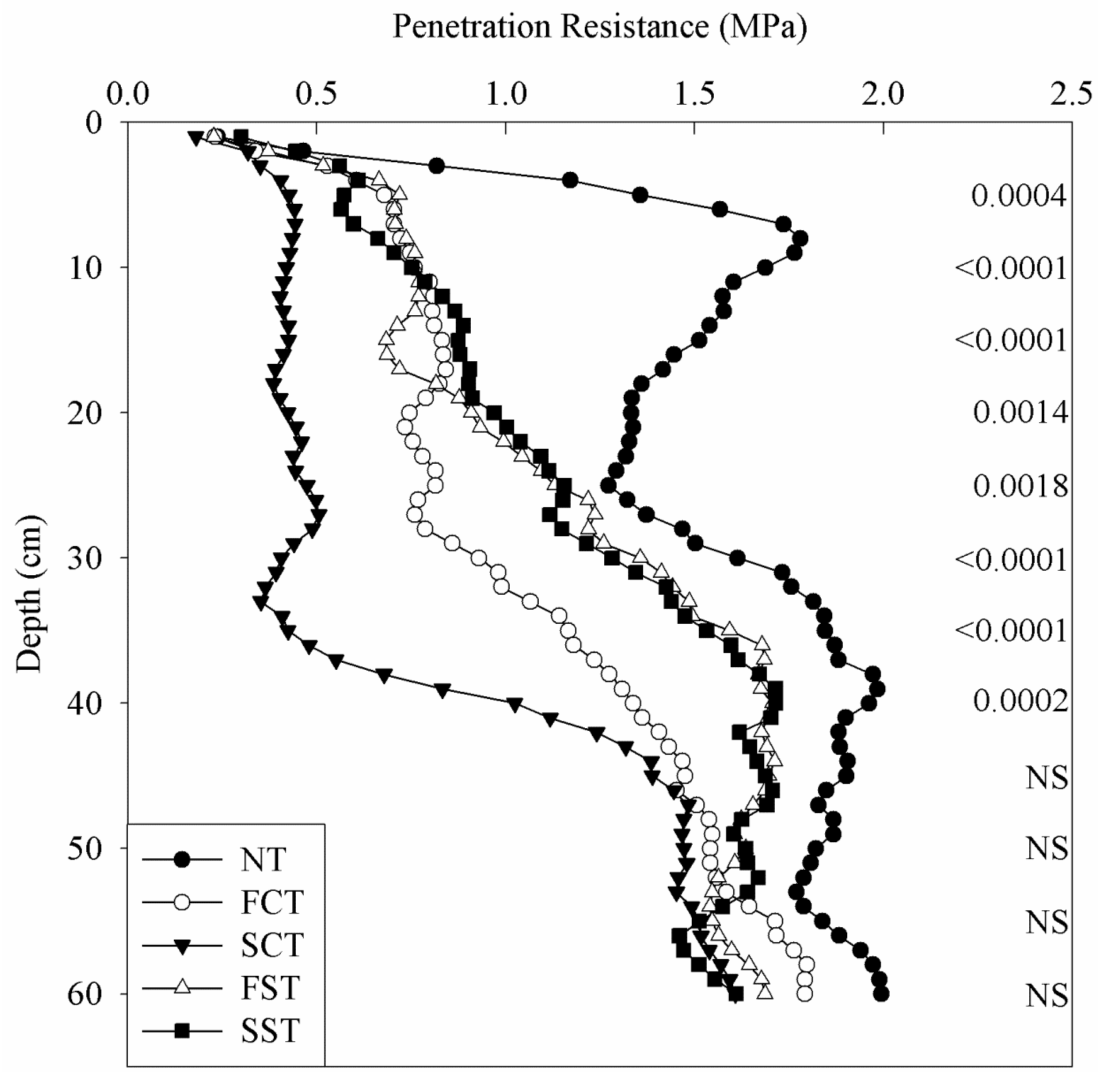

Fig. 2. Tillage effects on penetration resistance to a depth of 60 cm at Cache Junction, UT in 2013. Penetration resistance measurements were taken every cm but the P values shown on the right are only for every fifth cm. NT, no-till; FCT, fall conventional tillage; SCT, spring conventional tillage; FST, fall strip-till; SST, spring strip-till.